Arab American University-Palestine

Faculty of Graduate Studies

Indoor Radon-222 Concentration Levels, Annual Effective dose, and Exhalation rate Measurements in Dwellings of Al-Hashimy and Burqin Suburbs in Jenin District, During the Winter Season of the Year 2021

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This thesis was submitted in partial fulfillment of the requirements for master's degree in physics

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Declaration

The work presented in this thesis, unless otherwise referred to, is my researcher's own work and has not been submitted to elsewhere for any other degree or qualification, from any other academic foundation .

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Date: 06/8/2022.

To My Parents, Ηατεμ ανδ Νιδαα

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Owais Hatem Hamdan

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Abstract

In this study, the indoor radon-222 concentration levels (C_{Rn}), the annual effective dose (H_E) and exhalation rate in some dwellings of Al-Hashimya and Burqin Suburbs, Jenin district, Palestine. Using Solid State Nuclear Track Detector (SSNTD) type CR-39.

The C_{Rn} levels in Al-Hashimya were found to vary from 1.6 Bq./m^3 to 163.8 Bq./m^3, with an average value of 26.8 Bq/m^3, and from 5 Bq./m^3 to 207.4 Bq/m^3 in Burqin with an average values of 32.4 Bq/m^3.

The average values of the annual effective dose in in Al-Hashimya and Burqin suburbs are 0.68 and 0.82 mSv/y ;respectively.

The Exhalation rate were found to vary from 0.2 (milli Bq./m^{2}hr) to 21.7 (milli Bq./m^{2}hr) in Al-Hashimya , with an average value of 3.6 (milli Bq./m^{2}hr), and from 0.67 (milli Bq./m^{2}hr) to 27.5 (milli Bq./m^{2}hr) in Burqin with an average value of 4.3 (milli Bq./m^{2}hr).

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Abbreviation

SSNTD's	**Solid State Nuclear Track Detector's**
EPA	**Environmental Protection Agency**
WHO	**World Health Organization**
ICRP	**International Commission on Radiological Protection**
NRPB	**National Radiological Protection Board**
HVR	**Heat Recovery Ventilator**
Bq/m^3	**Becquerel per cubic meter**
pCi/L	**pico-Curies per Liter**
C_{Rn}	**Indoor radon concentration levels**
H_E	**Annual effective dose**
CR-39	**Colombia Resin -39**
α- particle	**Alpha particle**
β -particle	**Beta particle**
γ- particle	**Gamma particle**
UK	**United King**
SN :	**Serial Number**
REF :	**Reference Number**

Chapter One: Introduction and Literature Review

1.1: Introduction

Radiation is a sort of energy in the form of waves or particles. Humans are exposed to several types of radiation. Classified into two types, natural radiations, that include cosmic rays, terrestrial, internal and Radon radiation. The second type is the artificial radiation, it produced by X-ray machine and nuclear reactions .

Human exposure to natural sources is due to almost all materials surrounding us, that contain a percentage of radioactive materials such as Uranium, thorium, Radon,.. etc. [1] .

Rocks and the soil of the Earth both contain uranium naturally. It first decomposes into a gas known as radium, which then undergoes a series of decay events to produce radon gas.

Radon gas infiltrates through soil and rocks to facilities and homes, where it can be inhaled. It enters the human body to settle in the lungs and decomposes, producing alpha particles that stick to the walls of the alveoli, causing cancer . [2]

The continuous exposure of humans to radiation, will have a bad effect on human health. It may affect the human gene order or constituents , leading to a genetic defect that might appear in the coming human dynasty [3]

Figure 1.1 show that a pie chart that breaks down everyday radiation exposure sources according to research conducted by scientists in England.[4]

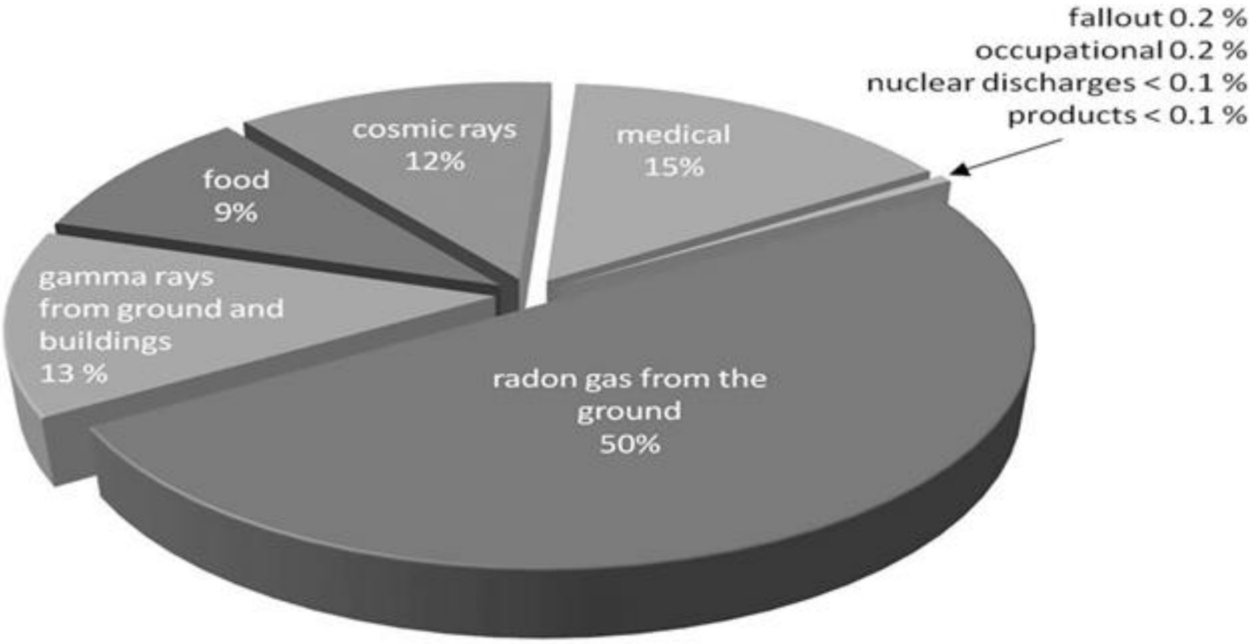

Figure 1.1 : Percentage share to different types of ionising radiation affecting the human body

Figure 1.1 show radon accounts for 50% of natural radioactivity exposure due to its gaseous state, inherent mobilization and high indoor build-up potential. [5]

Radon can enter through cracks in the foundation walls or floor slabs or unfinished floors, which contain some cracks, it can also tunnels construction joints, gaps around water pipes, window casements, floor drains and cavities inside walls.

Radon levels in homes depend on several factors such as their design and construction ,the property's bedrock type, soil type and soil moisture level.

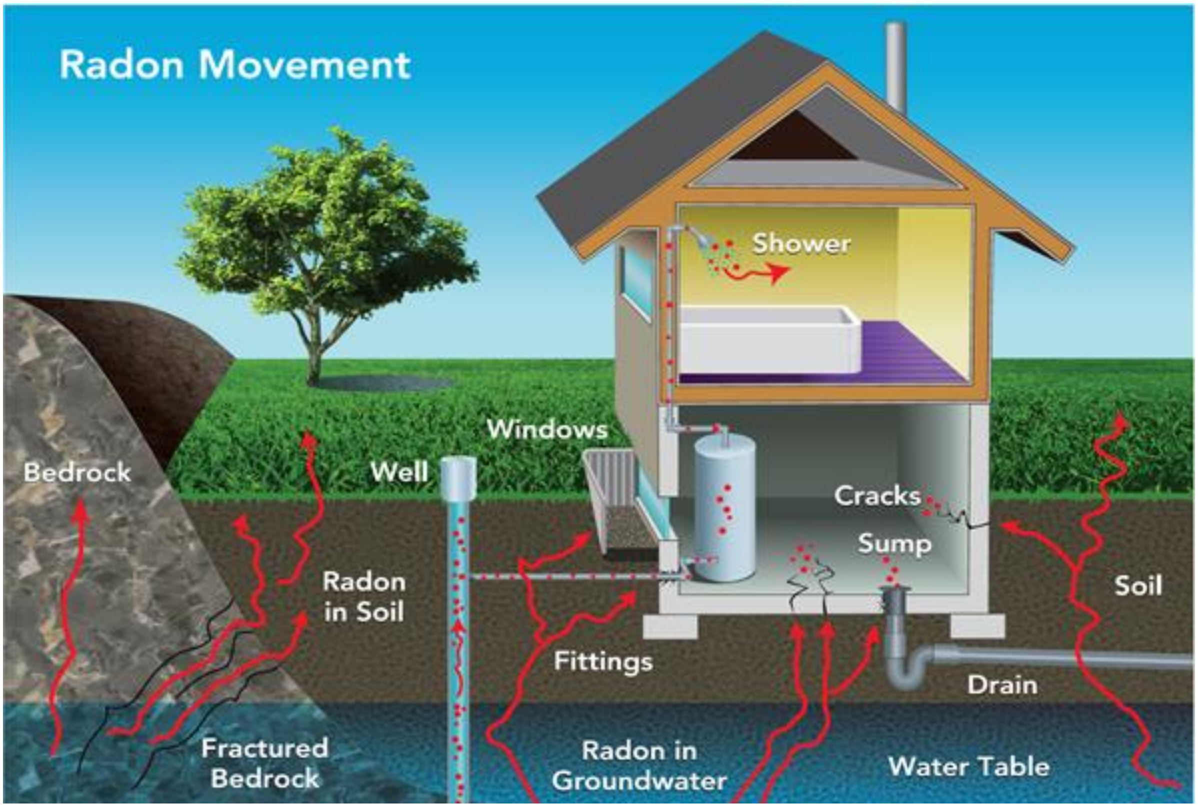

Figure 1.2 : Show how does radon enter a home . [6]

1.2 : Atomic and Nuclear Radiation

Ionizing radiation are generating characterized by their ability to excited and ionized atoms of matter with which they interact. The energy needed to cause a valence electron to escape on atom is of the order 4-25 eV.

Both natural and artificial radiation can release ionizing radiation in the form of alpha, beta, gamma, neutron and X-rays radiation. All of these have an radioactive effect on human health by introducing free radicals that interact with other compounds in the human body.

All types of radiation are caused by unstable atoms (or nucleus) , which have either an excess of energy or mass (or both). In order to reach a stable state, they must release that extra energy or mass in the form of radiation like Beta, alpha particles and Gamma rays.

1.2.1: Alpha radiation

Alpha radiation An alpha particle has two protons and four neutrons . It is therefore equivalent to a helium nucleus and is the heaviest of the particles emitted by radioactive isotopes. Alpha particles are usually emitted by heavy nuclei and can only have discrete amounts of energy, i.e. they give a line energy spectrum.

The probability of a collision between particles increases with the size of the particles, therefore, the rate of ionization in a medium traversed by particles emitted by radioactive isotopes increases with the size of the particles, and so does the rate of energy loss from the particles, Consequently, the penetrating power of the large alpha particles is relatively low.[7]

Alpha particles are unable to penetrate the outer layer of skin cells, but are capable, if an alpha emitting substance is ingested in food or air, of causing serious cell damage. Alexander Litvinenko is a famous example. He was poisoned by polonium-210, an alpha emitter, in his tea [8] .

1.2.2: Beta radiation

Beta radiation :a particles can be considered as very fast electrons. They are therefore much smaller than alpha particles, so they have greater penetrating power, they can be stopped by thin sheets of paper or metal. [7].

1.2.3: Gamma radiation

Gamma radiation (ϒ) is electromagnetic waves in nature and therefore has no charge or mass. Its wavelength is much shorter than that of visible light or radio waves

ϒ -radiation has well-defined amounts of energy. It occupies very narrow regions of the energy spectrum because it is produced by transitions between energy levels within the nucleus, so; it has a high energy.

ϒ- radiation has a very high penetrating power. Considerable amounts are capable of penetrating lead bricks 50 mm thick; ϒ photons with an energy of 1 M eV lose less than 1 % of their energy when passing through half a mile of air. [7]

1.2.4: Neutron radiation

Neutron radiation is a process that occurs when the nucleus is unstable, producing free neutrons.

Neutrons were discovered in 1932 when light elements (e.g. beryllium and boron) were bombarded with alpha-particles, for laboratory purposes, this is still a convenient method of production, but the most useful and intense source is the nuclear reactor, where neutrons are produced as a byproduct of fission of fissile material such as uranium-235.

Free neutrons are unstable and decay into a proton and a low-energy beta particle. When neutrons are produced, they can have a wide range of energy, from several M eV electron volts in fast neutrons to fractions of eV in thermal neutrons. [7]

1.2.5: X-rays

X-rays are similar to gamma radiation, with the primary difference being that they originate from the electron cloud. This is generally caused by energy changes in an electron, such as moving from a higher energy level to a lower one, causing the excess energy to be released. X-Rays are longer-wavelength and (usually) lower energy than gamma radiation, as well. [7]

Radiation particles such as alpha, beta, and gamma, are produced during natural radioactivity decay processes and released into the atmosphere, soil and water depending on where the radioactive material might be located.

Radon gas is classified among the natural radioactive sources and it is found in all rocks and soil. It can also be found in groundwater. Radon escapes easily from the ground into the air, where it decays and produces alpha particle, which have an impact on human health, that enter the body through air, water or food. It's deposited on the cells lining the airways, where they can damage DNA and may cause lung cancer. [9]

1.3: Radon Overview

Radon is a gaseous element that was discovered in 1899 by the scientists Owens.B.R.and Rutherford.E [10] . It belongs to the group of Noble or inert gases (He, Ne, Ar, Kr, Xe, Og) in the periodic table of elements. Characteristics of radon are summarized in the following table.

^{222}Rn	
Atomic number	86
Atomic weight	222 U (unit atomic weight)
Half-time	3.8215 day
Decay chain	^{238} U
Parent isotope	^{226} Ra
Decay product	^{218} Po

Table 1.1: physical properties of Radon $^{222}_{86}Rn$.

Radon as a radiation factor of the environment is a chemically inert radioactive gas, occurring naturally as an indirect decay product of uranium.

Radon gas is seven and a half times heavier than air which leads to its presence always below, and it mixes almost uniformly with the indoor air of homes, as radon concentration inside homes in general is 2 to 10 times higher than outside, [11] .

It's more existing in places where its geology is composed by radium and uranium minerals. The decay chains of radon can be found very far away from its origin, because its high solubility in water.

1.4: Isotopes of Radon

Natural Radon has several isotopes, such as, ^{219}Rn, ^{220}Rn, and ^{222}Rn.

The first isotope is Actinium (^{219}Rn): which has usually neglected concentration levels, because it has a small natural radiation dose, as well as it has a short half-life (3.92 sec.) , Therefore, it decays before leaving the soil to the environment.

Secondly, thoron (^{220}Rn) whose contribution level is negligible due to its shorter half-time (55 sec.), and whose contribution to inhalation dose are ignored, because of the presence of other more significant natural radiation.

Thirdly, is Radon-222, Radium emanation, (^{222}Rn). ^{222}Rn is classified as the most harmful important isotope, as it emits the energetic alpha- particle.

A product as a result of ^{238}U decay chain , it is present in the natural environment. [12]

Table(2.1) show the three isotopes of radon, the chain them belong it , half- life for each element and the type of radiated particles, also in Figure 1.2 the chains that come with these three isotopes .

Radon Isotope	Symbol	Decay Chain it belong to	Half –life	Particles radiated
Radon	^{222}Rn	^{238}U	3.82 day.	Alpha
Thoron	^{220}Rn	^{232}Th	55 sec.	Alpha & Beta
Actinon	^{219}Rn	^{235}U	3.92 sec	Alpha

Table 1.2: Natural isotopes of radon element and some related characteristic .

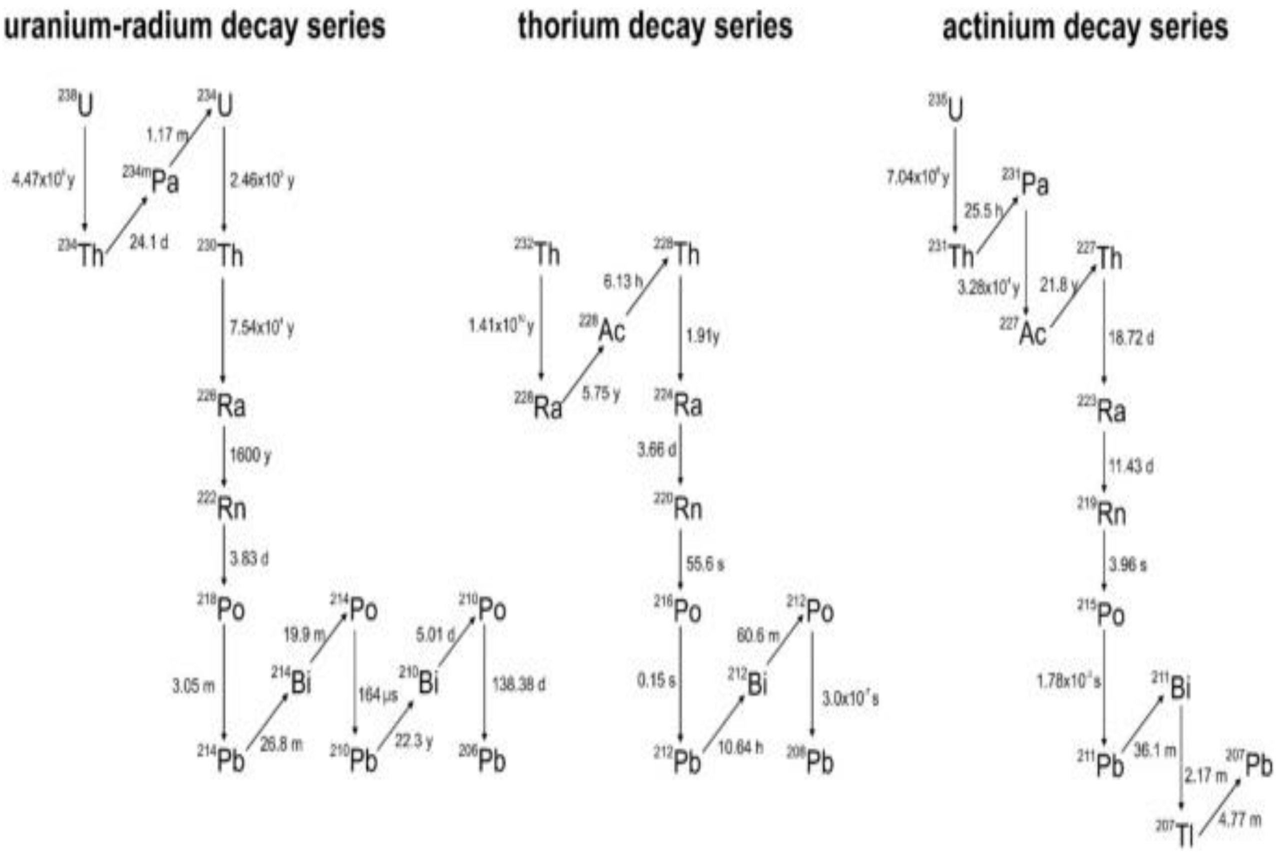

Figure 1.3 : Decay series isotopes for radon elements

This master thesis focuses on measurement of indoor Radon concentration levels in two of suburbs in Jenin district, names Al-Hashemya and Burqin regions.

1.5: The radiation activity Units

The activity concentration level of radon can be expressed in terms of the following units:

1.The Curie per liter: Ci/liter. Here, Curie is the number of disintegrations per second occurring in a mass of 1 g of ${}^{222}_{86}Rn$, which that equal 3.7×10^{10} disintegrations per second.

The most used unit is the picocuries (pCi=10^{-12} Ci) per liter of air (pCi/liter).

2.The Becquerel (Bq.) per cubic meter (Bq/m^3), defined the SI unit of radiation. Generally speaking

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

$$1 \text{ pCi/liter} = 37 \text{ Bq/m}^3.$$

Here the Becquerel (Bq.) is an activity unit that is defined as disintegration transformation per second . The concentration of radon in air is measured by the number of transformations that occur in a cubic meter of air per second (Bq/m^3).

1.6 : Radon Concentration levels

Radon gas is capable of exhaling from the earth's crust and from building materials, which are the main sources of this gas in outdoor and indoor spaces through pores of soil and water. It infiltrates through pipes, cracks and micro cracks in the ground that are in contact with the soil [14]. The infiltration of radon gas ^{222}Rn from soil has been identified as one of the most important mechanisms affecting indoor radon levels in many buildings. It has been reported that, on average 60.4% of indoor radon originates from the soil and surrounding soil of buildings worldwide [15].

The concentration of radon gas in soil gases is usually very high, of the order of tens of thousands of Bq/m^3 . Therefore, even small influxes can significantly increase indoor radon concentrations. The influx of radon from the soil is due to the pressure difference between the external and internal pressures in the lower part of the house structure and is the result of the coupling between the building and the soil.

1.7: Safe Limit Radon Concentration Levels (C_{Rn})

During the last four decades, a big concern worldwide to investigate the indoor as well as the outdoor radon concentration levels, it order to reveal its effect on human. International and national agencies were concerned with the environmental protection in countries that are categorized as places of high radon concentration levels to guide their citizens about the seriousness of the rate gas. A wide investigation conducted worldwide. Most countries have been used the data to establish their own standard levels that can't be exceeded and beyond that actions should be taken for public safety, assigned by international foundations.

It is worth mentioning here, that there is no unique reference level in this context to be adopted as the safest level in terms of protection of human health.

In table 1.3: some reference levels to guideline antinational organizations that intent of mark indoor radon concentration levels

Organization	Reference Guideline level (Bq/m^3)	Reference
WHO	100	Baluci, C., Vincenti, K., Tilluck, B., Conchin, S., Formosa, S., & Grech, D. (2013). National mapping survey of indoor radon levels in the Maltese Islands (2010-2011).
ICPR	300	Harrison, J.D., and J.W. Marsh. "ICRP Recommendations on Radon." *Annals of the ICRP* 49, no. 1_suppl (December 2020): 68–76.
EPA	ural isotopes and some ic .	Mowlavi, A. A., Fornasier, M. R., Binesh, A., & Denaro, M. D. (2012). Indoor radon measurement and effective dose assessment of 150 apartments in Mashhad, Iran. *Environmental monitoring and assessment*, *184*(2), 1085-1088.
UK	200	World Health Organization. (2009). *WHO handbook on indoor radon: a public health perspective*. World Health Organization.
Germany	250	World Health Organization. (2009). *WHO handbook on indoor radon: a public health perspective*. World Health Organization.
NRPB	200	: Baluci, C., Vincenti, K., Tilluck, B., Conchin, S., Formosa, S., & Grech, D. (2013). National mapping survey of indoor radon levels in the Maltese Islands (2010-2011).

Table 1.3 : Reference guideline indoor radon concentration levels for some organization .

1.8: Literature review

Many researchers worldwide, have been investigating radon gas concentration levels and diffusion coefficient emitted from building materials. A tremendous publications (more than 37000 articles) have been completed in this field [16,…,25]

Here is a set of the most recent studies (global, Arab and local) in this regard:

1.8.1: Global studies

in 2021, Measurements of indoor radon levels in all districts of a Public Healthcare in Italy, were performed using nuclear track detectors, CR-39. It's results of radon concentrations varied from 7 Bq/m^3 and 5148 Bq/m^3 , with an average value of 67 Bq/m^3 [16] .

A study in 2021, covered most of the territory of Latvia that located in the Baltic Sea region of Northern Europe, conducted 941 radon measurements, The study found that 94.7% of samples did not exceed the national permissible limit (200 Bq/m^3) the median value of average specific radioactivity of radon was 48 Bq/m^3.

Industrial workplaces had wonderfully low radon levels due to strict requirements for air quality and proper ventilation. [17]

in 2020 , a test radon performed in the Campania region (Southern Italy), were carried out 127 confined spaces at underground and 9 confined spaces at ground floors by using CR-39 solid-state nuclear track detectors, Radon levels were found to be between 17 and 680 Bq/m^3, with an average of 130 Bq/m^3 , About 7% of the results gave activity concentration above the reference value that determined it the Italian legislation on radiation protection for the activity concentration of radon at 300 Bq/m^3. [18].

In 2020, Radon surveys; conducted in four Russian cities (Ekaterinburg, Chelyabinsk, Saint-Petersburg and Krasnodar), carried out 478 fats by using CR-39 nuclear track detectors, with the smallest average radon concentration observed in panel and brick houses built according to standard projects of 1970–1990 by average 21 Bq/m^3 and the highest average by 49 Bq/m3 in new energy efficient buildings. [19].

In winter 2019, a study evaluated the concentration of radon in residential houses and public places in Firuzkuh city in Iran by CR-39 detector, where the mean results 137.74 $Bq./m^3$ in homes and 110.17 $Bq./m^3$ in public places.[20].

In 2019, Jamshid Soltani-Nabipour, Abdollah Khorshidi, and Farideh Sadeghi measured Radon concentration in three different floors by a detector had been manufacture and compared it with Alpha-Guard detector. he maximum result was in the underground floor covered by plaster and cement, so that was 347 Bq./m^3 by the made detector and 304 Bq./m^3 by Alpha-Guard detector. The minimum result was on the first floor covered by the same materials, so that was 58 Bq./m^3 and 47 Bq./m^3 by Alpha-Guard detector. [21].

In 2019, scanned Gachin Rural District in Hormozgan Province, Iran by solid-state detectors CR-39 to measure the radon concentration levels in that region it was found that 94% of the results were under the reference value that market it the World Health Organization (WHO) at 100 Bq/m^3, the mean radon concentration was 53.20 Bq/m^3 [22].

1.8.2 : Arabian studies

In 2019, measurements of indoor radon concentrations and annual effective dose in the western and southwestern regions of Saudi Arabia in a total of 1119 dwellings, the indoor radon concentrations ranged from 11 to 137 Bq/m^3 with an overall mean of 32 Bq/m^3 for all investigated houses. The overall annual mean effective dose rate from radon and its decay progenies was estimated to be 0.76 mSv/y. [23]

1.8.3: local studies

In 2020, study has been done in dwellings of Tammon village . The area was devided to five sections. Indoor radon concentration levels were varied from 16.07 to 56.6 Bq/m^3, with an average value of 28.98 Bq/m^3.

The annual effective doses varied from 0.45 mSv/y to 1.59 mSv/y , whith an average value of 0.74 mSv/y [24]

In 2015, researchers Mohammed Abu-Samreh , Anan Hussain and others measured the indoor radon concentrations in 87 different rooms in Tobas city in Palestine for 3 months, included the apartments, stores, schools, and warehouses. They have used CR-39 solid-state nuclear track detectors. The average values of radon concentration levels in apartments, stores, schools, and warehouses were (154.2 , 116.5 , 168.5 , and 112.5) Bq./m3 respectively, and the average annual effective dose in these places was (3.86, 2.91, 4.21, and 2.81) mSv/y. [25]

1.9: Study Problem

Radon concentration levels and exhalation rate in buildings and facilities in Burqin and Al-Hashimya districts in Jenin-city were not previously investigated.

Investigation of radon concentration levels has a great importance for the determination of population-level exposure to radiations. As most of the residents spend about 80% of their time inside the buildings, their exposure to indoor radon radiation become more and more, the probability lung cancer risk will be more high , especially if their homes had bad ventilation conditions. [26]

For the above-mentioned reasons, we plan to study the concentration of radon and the exhalation rate for indoor radon in the selected areas in order to shed light on radon radiation hazard and for its impact on the health of people.

According to the obtained results, mitigation solutions will be proposed for homes having high concentration levels of radon gas.

These may include warning people of the hazardous health effects of the gas and advise them to improve their ventilation conditions so that radon concentrations levels should be kept within or below the assigned international standard values.

Data obtained will serve as a data base to compare the radon exposure of the whole studied area with the globally assigned values. This will also be helpful to explore the radiological hazard of this radioactive gas to the urban population, We hope that this study will pave the way to create a map of radioactive radon exposure for the entire district of Jenin in the future. We look forward to have Palestinian limits and standards that can be fully implemented in the Palestinian territories as in many other countries around the world.

Chapter Two: Experimental Details

2.1: Introduction

The fact that radon cannot be perceived by the human senses has led to the development of numerous measurement techniques and procedures to collect data on radon concentration levels. Radon measurement is mainly concerned with measuring radon activity, which is the rate at which radon atoms decay, since the activity is proportional to the number of radon atoms present.

In this study, the process of measurements has be done by special detectors to Radon gas, which is type of 39-CR. The detectors a plastic polymer has an area of 1 cm^2 that serves as a detector of alpha particles released by radon gas in the environment. The abbreviation stands for "Columbia Resin #39", which was the 39th formula of a thermosetting plastic developed by the Columbia Resins project in 1940. [9]

CR_39 was exposed to the EPA action level of 4 pCi/L (148 Bq/m^3) radon for 3 months. This is the level at which EPA recommends remediation. The EPA also points out that radon levels below 4 pCi/L are still a health risk. It can be reduced in many cases if there is a need to reduce radon concentrations in indoor air, EPA recommends hiring a certified radon reducer to ensure that appropriate methods are used to reduce radon concentrations.

2.2: Study Areas

This study focuses on two regions of Jenin province , namely Al-Hashimya and Burqin areas . Both of them are considered to be rural regions "according to the classification of village types and cites approved by the Palestinian Central Bureau of Statistics".

Al-Hashimya region is located according to the Degrees Minutes Seconds (DMS) system between two longitudes 35^o 12' 30" and 35^o 14' 15" east of the Greenwich line and between latitudes 32^o 27' 15" to 32^o 28' 30" north of the equator, it is 350 m above sea level and 8 km west of Jenin . The overall area is about 2.721 Km^2 [27]. The population of region is 1305 people, according to the Population, Housing and Trade Census - 2017.[28]

Burqin region is located according to the (DMS) system between longitude 35^{o}14' 15" and 35^o 16' 45" east of the Greenwich line, and between latitudes 32 ^{o} 26' 15" to 32 ^{o} 28' 30" north of the equator, It is 5 km west of Jenin, it rises 270 m above sea level. It surrounds the areas of Kafr Dan, Jenin, Qabatiya and Kafr Qud. According to the 2017 population and housing census, 7126 people lived it. [28] , both sites are exhibited in Figures (2.1 to 2.3)

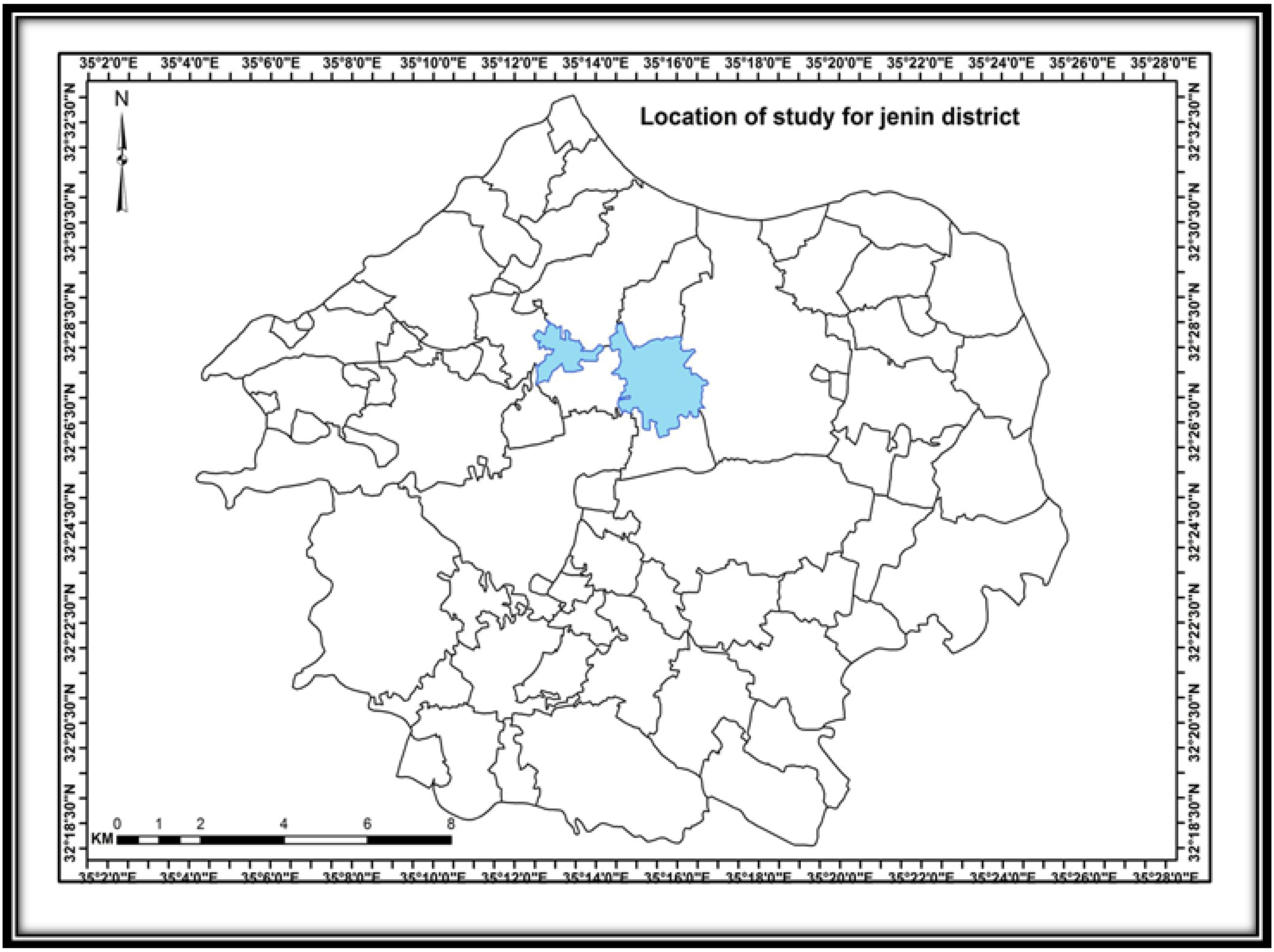

Figure 2.1 : Shows the location of Jenin City for latitude and longitude .

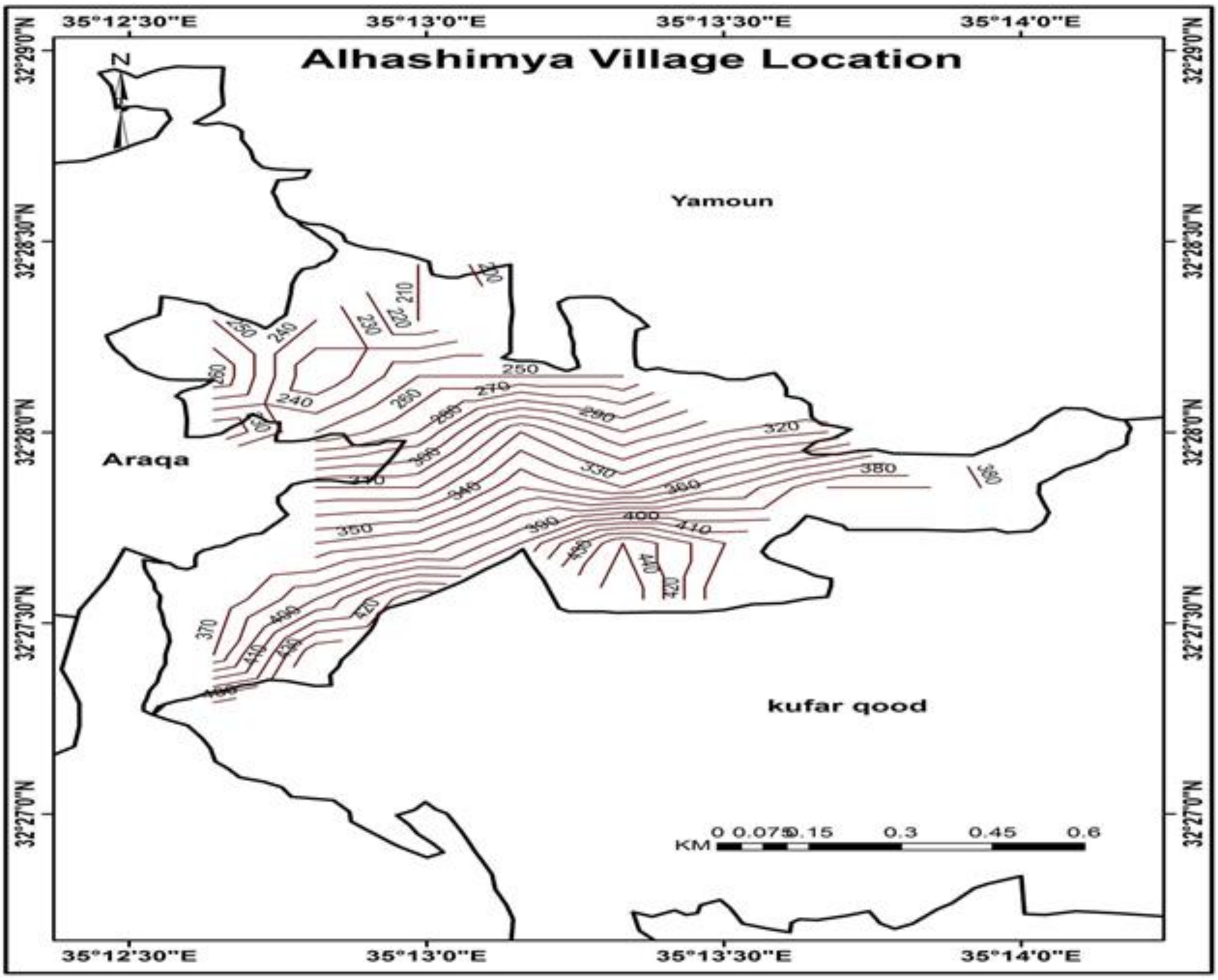

Figure 2.2: An image showing a map of Al-Hashimya with respect to latitude and longitude

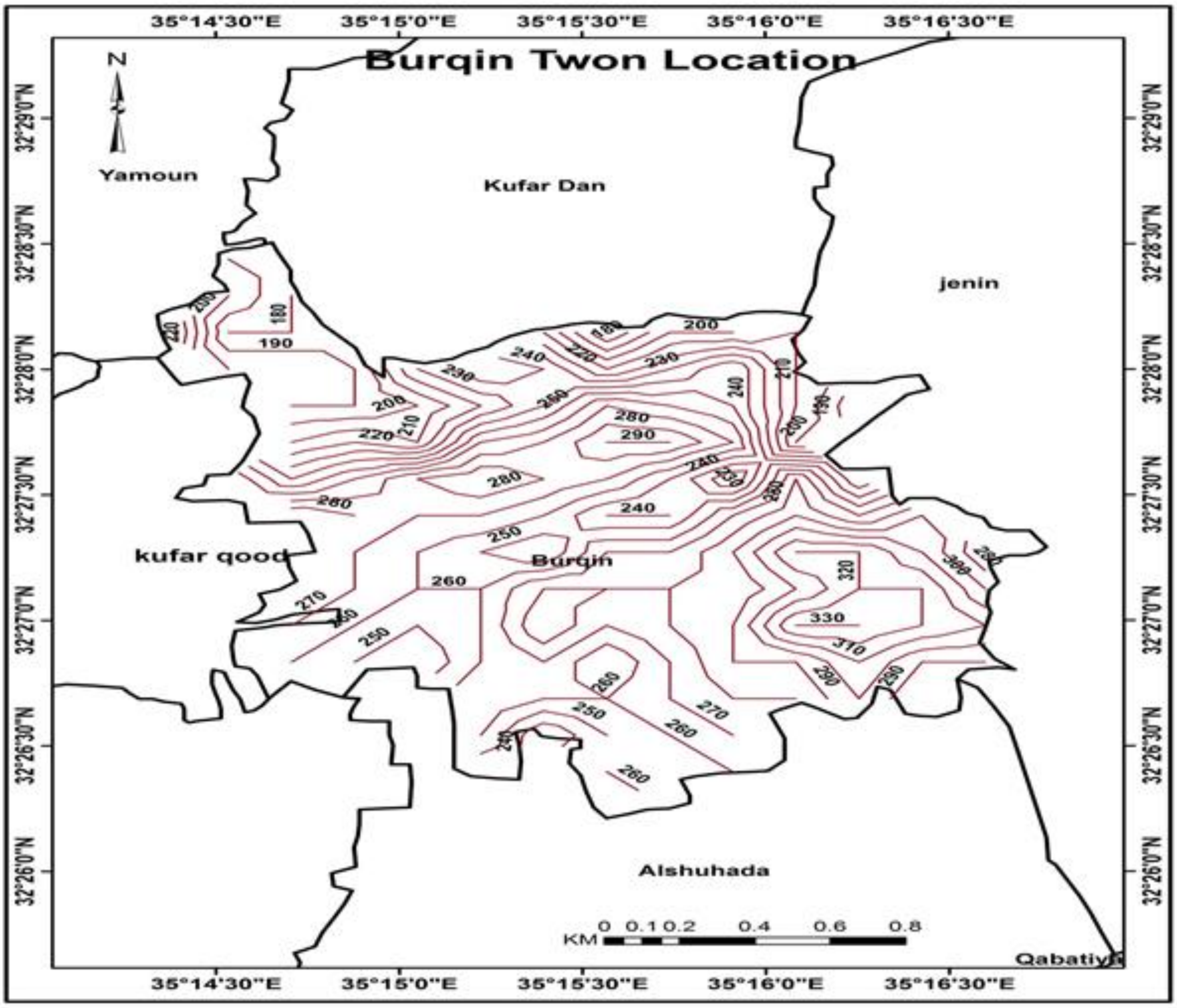

Figure 2.3 :An image showing a map of Burqin village for latitude and longitude

2.3: Background of samples

The long term method, or SSNTD (CR-39) were employed to investigate radon concentration levels worldwide . The method is based mainly on preparing CR-39 track detectors to place them in buildings, about 60 cm above the ground.

For a long period of time, ranging from 1 week to 1 year to have the best data for levels throughout the year, because radon levels change with seasons. They are also better suited for evaluating radon exposure over long periods of time at a moderate cost.

After radon gas decays, alpha particles are released as a decay product. They strike the detectors and break the chemical bonds of the polymers, leaving a permanent effect called a track. It can be observed and counted with a microscope after exposing the detector to a caustic solution to magnify the tracks left by the particles. This safe and simple process is called etching.

Therefore, chemical treatment (etching) is required to examine these dots (traces). This can be achieved by, first immersing the detectors in an alkaline solution such as sodium hydroxide (NaOH) or potassium hydroxide (KOH), which are strongly capable to etch the surface of the polymer.

Secondly; heating the detector at 70 °C for a certain period of time (about 6 hours) to show the effect of the alpha particles. Thirdly, the detectors were washed by distilled water. This allows counting the alpha particle tracks using a magnified microscope, where the tracks appear as bright areas under microscope at magnification.

The alpha particle trace density points are directly proportional to the radon concentration in air [29].

The shape and size of each track provides additional information about particular particles because the energy level of a particle can be read from the size of its track. The direction from which the particle struck the leaf can be determined by the circular or elliptical shape of the track at the point of contact.

This high level of visual detail, along with simplicity and cost effectiveness, is cause CR -39 is making its own mark on the industry as a branch of SSNTD materials.

2.4: Experimental Details

The CR-39 detectors were placed in special plastic cups with a length of 6.5 cm and a diameter of 5 cm and 7 cm (see Figure 2.4). The cups were covered with a transparent cover to prevent dust and dirt from entering.

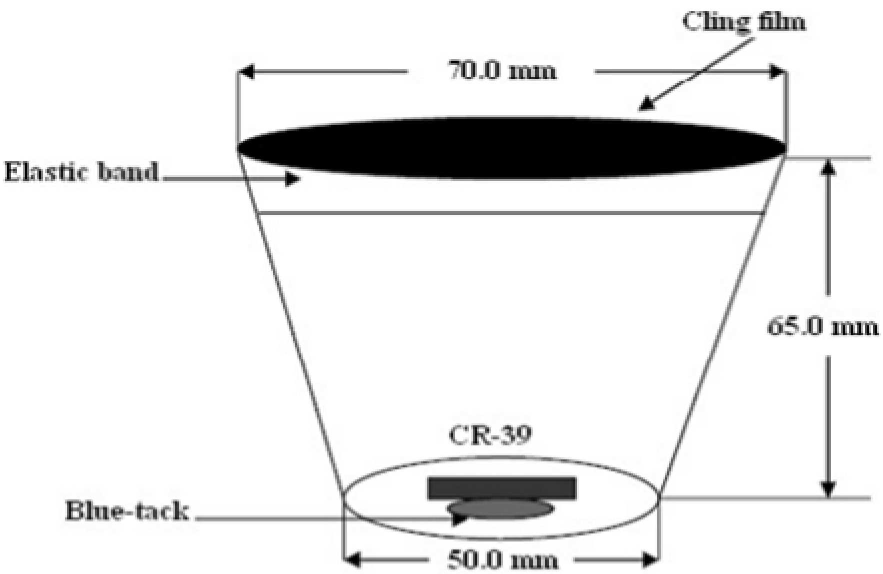

Figure 2.4 : Shape of container of CR-39 detector.

A Subtotal of 102 detectors were prepared and distributed among dwelling of the investigated areas, 11 sensors have been lost or destroyed (10.8 %) .

Samples were distributed on December 12, 2020 and collected again on May 24, 2021 after 164 days. After collecting the cups, the detectors were taken out of the dosimeter and prepared for etching.

The collected detectors were chemically etched with a 6.25 N solution of $NaOH$ at a temperature of 70o C for nearly 6 hours. At the end of the etching process, the detectors were thoroughly washed with distilled water to minimize dust and fingerprint effects and then they were dried. The number of etch spots (trace spots) on each detector was visually counted using an optical microscope, type Huma Scope Classic ^{LED}, Serial Number (SN)112006 ,REF (reference number) 14500 , at a magnification power of 100 x to count the alpha traces through the detectors surfaces . (Figure 2.5)

Figure 2.5 : Shows the microscope that was used in counting the traces of alpha particles , with some information as SN and REF

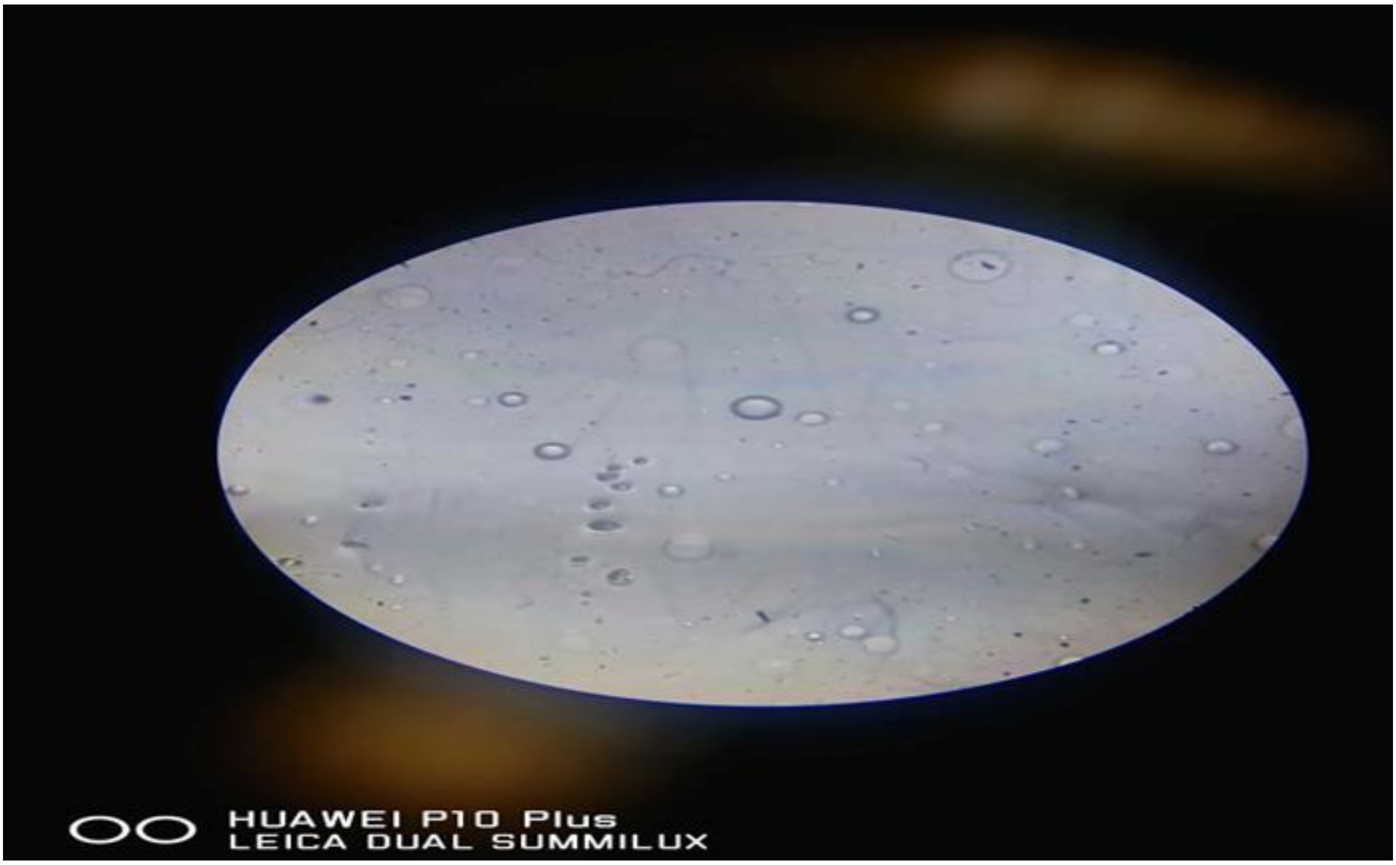

Figure 2.6. Exhibition Track points appeared in one of CR-39 detectors after etching process as seen by a microscope.

The trace spot (etching) on one of the specimens appears under the microscope at 100x magnification as a bright spot with a dark area around. It is exhibited in Figure 2.6 .

Chapter 3 : Results and Discussion

3.1 : introduction

In this chapter, the obtained data representing the density of traces for each detector, collected in the studied dwellings in the study regions (Tables A and B in appendix) are analyzed on a statistical basis to estimate the arithmetic mean of concentrations values ,annual effective dose and exhalation rate. The results are discussed and compared with the international standard for radon.

3.2 Measurement radon Concentration levels (C_{Rn})

The results of the average track density of ^{222}Rn presented in Table (A,B) for each detector were employed to calculate the radon concentration levels (C_{Rn}) in Bq/m^3 using the calibration factor obtained at Bristol University and adopted by Yarmouk research group , the radon concentration levels can be expressed in terms of track density as [30]

$$C_{Rn} = \frac{C_o t_o \rho}{\rho_o t} \qquad (3.1)$$

Where;

C_o : is a radon concentration in calibration chamber 90.0 kBq./m^3

t_o : is the exposure time of detector in radon chamber 2 days .

ρ: is the density of nuclear tracks measured in units of tracks/cm^2 .

ρ_o : is the density of nuclear tracks measured after its calibration, which equals 3.3×10^4 tracks/cm^2

t: is the exposure time of distributed detectors in days.

3.3 :Measurements of the annual effective dose (H_E)

3.3.1 : Absorbed Dose $\frac{dE}{dm}$

Absorbed dose is a dose quantity of the energy deposited in matter by ionizing radiation per unit mass.

the absorbed dose measuring by unit J/Kg or gray (Gy) , where gray is defined as one Joule of energy absorbed per kilogram of matter.

3.3.2 : Dose Equivalent (H_T)

Dose equivalent is intended to obtain the same degree of damage to each type of radiation .

Each type of radiation has a different harm, so each type has a different radiation weighting factor (W_R), X-ray , gamma rays , beta particles have weighting factor equal 1 , while alpha particles , fission products and heavy nuclei having a weighting factor equal 20 , that can measure the dose equivalent through equation

$$H_T = W_R \times \frac{dE}{dm} \qquad (3.2)$$

Dose equivalent can measure by product of W_R and H_A at a point in tissue, where $\frac{dE}{dm}$ is the absorbed dose and W_R is the quality factor for the specific radiation at that point.

The unit of equivalent dose is joule per kilogram (J/kg) or a special unite called sievert (Sv) [31] .

3.3.3 : Annual Effective Dose

The annual effective dose (H_E) for the inhabitants was calculated from the experimentally determined value of radon concentration levels (C_{Rn}) using expression (3.3) given by the following equation [32]

$$H_E = C_{Rn} \times F \times H \times T \times DCF \qquad (3.3)$$

Where, C_{Rn} is the calculated radon concentration levels in Bq./m^3 , F is the indoor equilibrium factor between radon and its progeny which equals to 0.4 ,H is the occupancy factor (0.8),T is hours in a year (8760 h/y) and DCF is the dose conversion factor (9 nSvm^3/hBq) for radon and its progeny.

The annual effective dose can be calculated by unit of milliSievert per year , where Sievert is the special name of unit Joule per Kilogram (J/Kg) .

3.4: Measurements of the Exhalation Rate (E_x)

The radon exhalation rate is defined as the rate of radon escapes from the materials to the atmosphere ,it can be measurements by unit of Bq./m^2.hr.

The increase in radon concentration levels in air of the room is as a result of radon exhalation from all the inner space of the room. The exhalation rate.

E_x (in milli Bq/m^2 .hr) was calculated using the following empirical equation [33] :

$$E_X = \frac{C_{Rn}\, TV\lambda}{A[T + \frac{1}{\lambda\left(e^{\lambda T} - 1\right)}]} \qquad (3.4)$$

Where V is the effective volume of the cup in m^3 ; (**λ** =7.6×10^{-3}/ hr) is the disintegration decay constant for radon ,T is the exposure time in hours and A is the area of the cup in m^2.

3.5: Results

Results obtained from the collected detectors, from both Al Hashimya and Burqin regions investigated in Jenin district ,were employed to calculate the Concentration levels, annual Effective Dose and Exhalation rate of radon , using equations (3.1-3.2 and 3.4, respectively) .

A summary of the indoor radon concentration levels results were measured in air of dwellings, selected randomly from the monitored zones during time period of December, 2020 to May,2021 .They were inserted in Tables (A and B) in the appendix.

Tables includes summary of the number of collected detectors (N) ,type of room , number of floors, tracks per 1cm^2, the concentration of radon (C_{Rn}) in (Bq/ m^3) ,annual effective doses (H_E) equivalent obtained (mSv/y) and the exhalation rate (E_x) by unit (milli Bq./m^{2}hr)

suburb	No. of detectors	Radon concentration (Bq./m^3)			Annual Effective dose (mSv/y)			Exhalation rate (milli Bq./m^{2}hr)		
		Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
Al-Hashimya	46	1.6	163.8	26.8	0.04	4.13	0.68	0.21	21.7	3.6
Burqin	45	5	207.4	32.4	0.13	5.2	0.82	0.67	27.5	4.3
All region	91	1.6	207.4	29.6	0.04	5.2	0.75	0.21	27.5	3.9

Table 3.1 : Minimum, Maximum and Average of indoor radon concentration levels, annual effective doses and Exhalation rate to study regions

In general, for all regions, the indoor radon concentration levels in all suburbs were found to vary from 1.6 to 207.4 Bq/m^3 with average value of 29.6 Bq/m^3 . The lowest concentration value of 1.6 Bq/m^3 was found in a guest room, whereas the highest concentration of 207.4 Bq/m^3 was found in a store.

The concentration levels in Burqin suburb varied from a minimum of 5 Bq/m^3 to maximum of 207.4 Bq/m^3 with an average value of 32.4 Bq/m^3 . In Al-Hashimya suburb it varied from a minimum of 1.6 Bq/m^3 to a maximum of 163.8 Bq/m^3 with an average value of 26.8 Bq/m^3 .

The annual effective dose in Burqin suburbs was varied from 0.13 mSv/y to 5.2 mSv/y with an average value of 0.82mSv/y and in Al-Hashimya suburb was varied from 0.04 mSv/y to 4.13 mSv/y with average value of 0.68 mSv/y.

The Exhalation rate of indoor radon gas in Burqin suburb ranges from 0.67 to 27.5 milli Bq./m^2hr , with an average value of 4.3 milli Bq./m^2hr and in Al-Hashimya suburb, that ranges from 0.21 (milli Bq./m^2hr) to 21.7 (milli Bq./m^2hr) , with an average value of 3.6 (milli Bq./m^2hr)

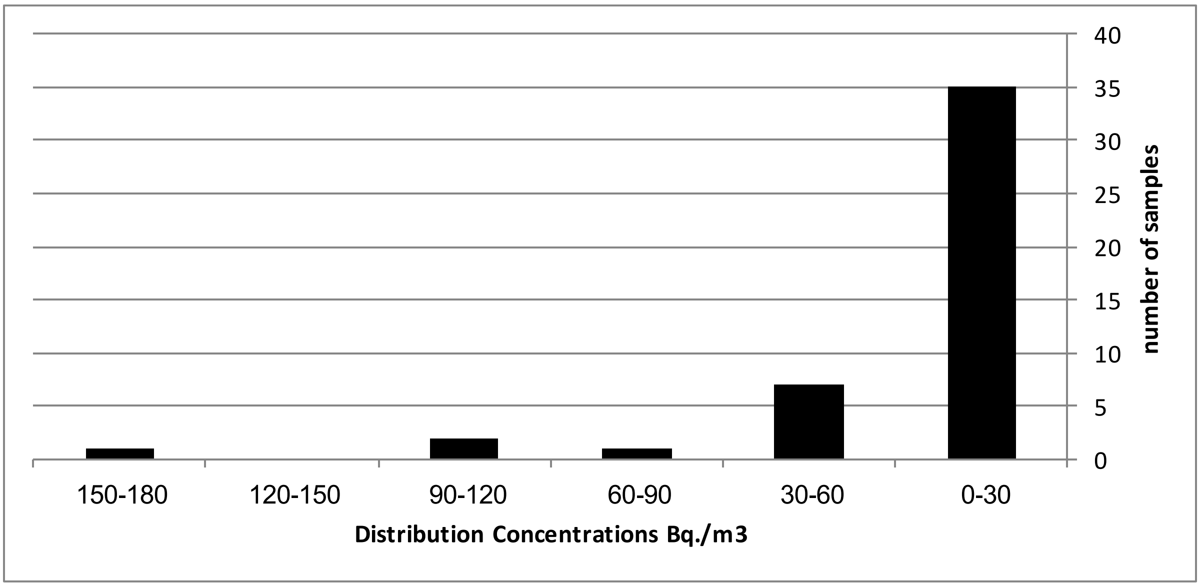

Figure 3.1 : Distribution Indoor Radon Concentration In Dwellings of Al-Hashimya.

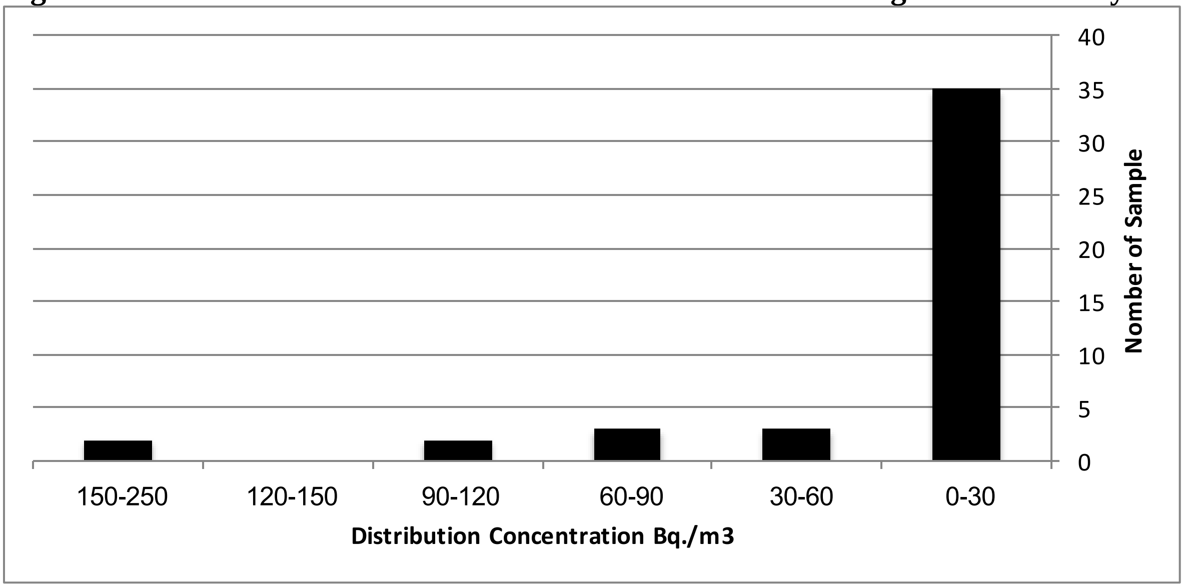

Figure 3.2 : Distribution Indoor Radon concentrations in Dwellings of Burqin.

Figures 3.1 and 3.2 show the distributions of indoor radon concentration levels in Al-Hashimya and Burqin, respectively.

It was found that 91 % of indoor radon concentration levels in test samples in Al-Hashimya and 95% of indoor radon concentration levels in Burqin were below of 100 Bq/m^3. This results is a good, because it's within the health range guideline of WHO .

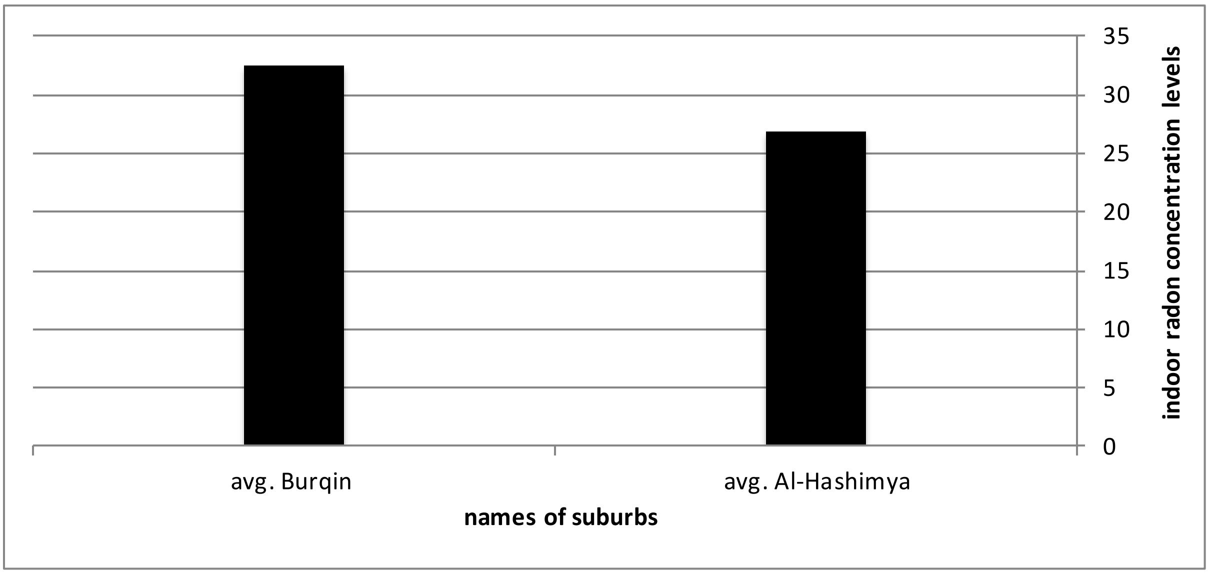

Figure 3.3 : average radon concentraton levels in each suburb

Figure 3.3 show the relation between average indoor radon concentration levels in each suburb, where the average concentration level in Burqin and Al-Hashimy Suburbs were 32.4 Bq/m^3 and 26.8 Bq/m^3; respectively .

Avg. H_E (mSv/y)	Avg. C_{Rn} (Bq/m^3)	Type room	max C_{Rn} (Bq/m^3)	Min C_{Rn} (Bq/m^3)	max H_E mSv/y	Min. H_E mSv/y	min E_x (milli Bq/m^{2}hr)	max E_x (milli Bq/m^{2}hr)
1.3	**50.3**	**Kitchen**	**163.8**	**10.1**	**4.13**	**0.25**	**1.34**	**21.74**
0.7	**26.4**	**Bedroom**	**84.9**	**5.5**	**2.14**	**0.14**	**0.72**	**11.27**
0.5	**18.5**	**Guest**	**77.8**	**1.6**	**1.96**	**0.04**	**0.21**	**10.32**
0.6	**24.4**	**Living**	**95.0**	**7.5**	**2.4**	**0.19**	**1.00**	**12.62**
0.8	**32.6**	**Stores**	**207.4**	**5.0**	**4.23**	**0.13**	**0.67**	**27.54**

Table 3.2 : Highest ,Lowest and Average of indoor radon concentration, annual effective dose and exhalation rate in the types of rooms

Table 3.2 : show maximum ,minimum and average values for indoor radon concentration levels (C_{Rn}), annual effective dose (H_E) and exhalation rate (E_x) , for each type of examined rooms

The examined rooms were divided to several types, kitchen rooms, living rooms, bedrooms, guest rooms and stores. The indoor radon concentration levels (C_{Rn}) ,annual effective dose(H_E) and exhalation rate for each of them were measurement and presented in tables [3.3 to 3.7]

Kitchen			
floor	**C_{Rn} (Bq/m^3)**	**H_E (mSv/y)**	**E_x (mili Bq/m^{2}hr)**
2	**10.7**	**0.3**	**1.42**
2	**10.1**	**0.3**	**1.34**
2	**25**	**0.6**	**3.32**
2	**91.9**	**2.3**	**12.21**
3	**32**	**0.8**	**4.25**
3	**28.2**	**0.7**	**3.74**
4	**10.2**	**0.3**	**1.36**
3	**24.1**	**0.6**	**3.20**
Avg. Burqin	**63.1**	**0.7**	**3.85**
2	**163.8**	**4.1**	**21.74**
2	**107**	**2.7**	**14.21**
Avg. Al-Hashimya	**135.4**	**3.4**	**17.98**

Table 3.3: Radon concentration levels, annual effective doses and Exhalation rate in kitchens.

Table (3.3) shows the measurements in kitchens, In Al-Hashimya it exceeded the limit permitted by WHO, which is 100 Bq/m^3 .It was found in 2nd floor, that it reaches to 163.8 Bq/m^3 and 107 Bq/m^3 .

For Burqin suburb, the results were not similar to the Al-Hashimya suburb. The results were less than the reference guideline adopted by the World Health Organization.

The reason for this high concentration in Al-Hashimya is activity of the granite element available in that kitchen, in addition to the lack of ventilation during the study period, especially since it was during the winter season .

To reduce values in kitchens might be due to using aluminum instead of granite in kitchen furnishing or good ventilation , which contributes to change the indoor air through the ventilation. To reducing the concentration of existing radon gas.

The annual effective dose in kitchen rooms in Burqin ranges between 0.3 mSv/y to 2.3 mSv/y , with an average value 0.7 mSv/y. Readings in Al-Hashimya were 4.2 mSv/y to 21.7 mSv/y, with an average value of 3.4 mSv/y.

The exhalation rate in kitchen rooms of Burqin varied from 1.34 milli Bq./m^2hr to12.2 milli Bq./m^2hr , with an average value of 3.8 milli Bq./m^2hr . The exhalation rate in Al-Hashimya reached 14.2 milli Bq./m^2hr to 21.7 milli Bq./m^2hr, with an average value of 17.9 milli Bq./m^2hr .

Living room			
floor	C_{Rn} (Bq/m^3)	H_E (mSv/y)	E_x (mili Bq/m^{2}hr)
2	24.1	0.6	3.20
2	13.2	0.3	1.75
2	95	2.4	12.62
3	20.6	0.5	2.73
3	18.2	0.5	2.42
3	16.2	0.4	2.15
2	72.7	1.8	9.66
1	15.1	0.4	3.20
1	10.5	0.3	1.75
Avg. Burqin	31.7	0.8	12.62

Table (3.4.a) : Indoor radon concentration levels and annual effective dose in living rooms of Burqin dwellings.

Living room			
floor	C_{Rn} (Bq/m^3)	H_E (mSv/y)	E_x (mili Bq/m^{2}hr)
2	19.2	0.5	2.55
3	7.5	0.2	1.00
2	12.9	0.3	1.71
2	19.2	0.5	2.54
2	28.0	0.7	3.71
3	8.8	6.7	1.17
3	8.8	6.7	1.17
Avg. Al-Hashimya	14.9	2.2	1.98

Table (3.4.b) : Indoor radon concentration levels and annual effective dose in living rooms of Al-Hashimya dwellings.

Tables (3.4.a and 3.4.b) show the measurements of indoor radon concentration levels, annual effective dose and exhalation rate in living rooms of Al-Hashimya and Burqin suburbs . The results are good for living rooms in both regions .

The concentrations were below the limit allowed by WHO (100 Bq/m^3) . The average radon concentration levels and annual effective dose in Al-hashimya and Burqin suburbs were 14.9 Bq/m^3 and 31.7 Bq/m^3, 2.2mS/y and 0.8 mS/y , respectively .

The exhalation rates in living rooms in Burqin suburb ranges between 1.4 Bq/m^2.hr and 12.6 Bq/m^2.hr with an average value of 3.4 Bq/m^2.hr, in living rooms of Al-Hashimya ; that ranges between 1 Bq/m^2.hr and 3.7 Bq/m^2.hr, with an average value of 1.9 Bq/m^2.hr

Guest room			
floor	C_{Rn} (Bq/m^3)	H_E (mSv/y)	E_x (mili Bq/m^{2}hr)
1	17.7	0.45	2.35
2	13.7	0.35	1.82
3	7.2	0.18	0.96
3	15.3	0.39	2.03
3	11.9	0.3	1.58
3	18.1	0.46	2.4
3	13.7	0.35	1.82
2	8.8	0.22	1.17
3	31.3	0.79	4.16
2	37.9	0.96	5.04
2	77.8	0.45	2.35
3	14.8	0.35	1.82
Avg. Burqin	22.4	0.18	0.96

Table (3.5.a) : Indoor Radon Concentration levels and annual effective dose in Guest rooms of Burqin dwellings .

Guest room			
floor	C_{Rn} (Bq/m^3)	H_E (mSv/y)	E_x (mili Bq/m^{2}hr)
1	22.9	0.58	3.04
2	7.9	0.2	1.06
3	17.7	0.45	2.35
1	25.0	0.63	3.32
1	20.5	0.52	2.72
2	5.5	0.14	0.72
3	7.8	0.2	1.04
2	13.5	0.34	1.79
4	1.6	0.04	0.21
4	21.8	0.55	2.89
3	18.0	0.45	2.39
2	1.6	0.04	0.21
2	15.4	0.39	2.04
1	37.8	0.95	5.02

Table (3.5.b): : Indoor Radon Concentration levels and annual effective dose in guest rooms of Al-Hashimya dwellings .

Tables (3.5.a and 3.5.b) shows the indoor radon concentrations levels, annual effective dose and exhalation rate in guest rooms of Al-Hashimya and Burqin suburbs.

In Burqin guest rooms, the concentrations are low, and they are in the safe limit . The average of indoor radon concentration levels and annual effective dose in Burqin guest rooms is 22.4 Bq/m^3 and 0.56 mSv/y; respectively.

The indoor radon concentration levels and annual effective dose in Al-Hashimya are low and in the safe rate for all guest rooms. The average of concentration level is 15.5 Bq/m^3 and annual effective dose is 0.39 mSv/y .

The exhalation rate in Burqin guest rooms varied from 0.9 milli $Bq./m^2hr$ to 10.3 milli $Bq./m^2hr$, with an average of 2.96 milli $Bq./m^2hr$. In Al-Hashimya, the exhalation rates ranges between 0.2 milli $Bq./m^2hr$ and 5 milli $Bq./m^2hr$, with an average of 2.06 milli $Bq./m^2hr$.

Bedroom			
floor	C_{Rn} (Bq/m^3)	H_E (mSv/y)	E_x (mili Bq/m^{2}hr)
2	84.9	2.1	11.27
3	24.4	0.6	3.24
3	17.7	0.4	2.35
3	15.0	0.4	2.00
3	19.2	0.5	2.54
3	17.9	0.5	2.37
Avg. Burqin	29.8	0.8	3.96

Table (3.6.a) : Radon concentration levels in Bedrooms of Burqin

Bedroom			
floor	C_{Rn} (Bq/m^3)	H_E (mSv/y)	E_x (mili Bq/m^{2}hr)
1	28.1	0.7	3.73
2	14.2	0.4	1.88
2	5.5	0.1	0.72
2	12.6	0.3	1.67
2	18.7	0.5	2.48
2	58.3	1.5	7.74
Avg. Al-Hashimya	22.9	0.6	3.04

Table (3.6.b) : Radon concentration levels in Bedrooms of Al-Hashimya

Tables (3.6.a and 3.6.b) shows the indoor radon concentrations levels, annual effective dose and exhalation rate in bedrooms of Al-Hashimya and Burqin suburbs.

The results of indoor radon concentration levels in bedrooms of dwellings Al- Hashimya are reassuring. The average radon concentration levels and annual effective dose is 22.9 Bq/m^3 and 0.6mSv/y , respectively .

The indoor radon concentration levels in Burqin were higher, but in the safe limit . The average concentration levels in bedrooms of Burqin dwellings is 29.8 Bq/m^3 and average of annual effective dose is 0.8 mSv/y.

The exhalation rate in Burq in sleep rooms varied from 1.99 (milli $Bq./m^2hr$) to 11.2 (milli $Bq./m^2hr$),with an average value of 3.9 (milli $Bq./m^2hr$) .

In Al-Hashimya, the exhalation rates ranges between 0.7 (milli $Bq./m^2hr$) and 7.7 (milli $Bq./m^2hr$), with an average value of 3 (milli $Bq./m^2hr$) .

Stores			
floor	C_{Rn} (Bq/m^3)	H_E (mSv/y)	E_x (mili Bq/m^{2}hr)
1	23.2	0.59	3.08
1	5.0	0.13	0.67
1	10.1	0.26	1.34
1	11.7	0.3	1.56
1	12.2	0.31	1.62
1	207.4	5.23	27.54
1	14.3	0.36	1.90
1	167.5	4.23	22.24
Avg. Burqin	56.4	1.42	7.49

Table (3.7.a) :Radon concentration levels and doses in Burqin Stores

Stores			
floor	C_{Rn} (Bq/m^3)	H_E (mSv/y)	E_x (mili Bq/m^{2}hr)
1	61.4	1.55	8.15
1	28.6	0.72	3.80
1	23.1	0.58	3.06
1	33.8	0.85	4.48
1	17.2	0.43	2.28
1	20.4	0.51	2.71
1	15.8	0.4	2.10
1	11.6	0.29	1.54
1	8.1	0.21	1.08
1	11.0	0.28	1.46
1	5.9	0.15	0.78
1	40.5	1.02	5.38
1	107.6	2.72	14.29
1	30.2	0.76	4.01
1	34.1	0.86	4.52
1	37.1	0.94	4.93
Avg. Al-Hashimya	30.4	0.77	4.04

Table (3.7.b) :Radon concentration levels and doses in Al-Hashimya Stores .

Tables (3.7.a and 3.7.b) shows the indoor radon concentrations levels, annual effective dose and exhalation rate in stores of Al-Hashimya and Burqin suburbs.

Two stores in Burqin exceeded the limited WHO for radon concentration , their concentrations are 207.4 Bq/m^3 and 167.5 Bq/m^3.

The annual effective dose for that stores are 5.2 mSv/y and 4.2 mSv/y; respectively .

The exhalation rates of the previously mentioned stores are 27.5 milli $Bq./m^2hr$ and 22.2 milli $Bq./m^2hr$; respectively.

One store in Al-Hashimya exceeded WHO limit , with a concentration of 107.6 Bq/m^3. The annual effective dose and exhalation rate for that store are 2.7 mSv/y and 14.2 milli $Bq./m^2hr$; respectively .

Chapter Four: Conclusions and Recommendations

4.1: Conclusions

After completing analysis of data and discussing the obtained results in previous chapter, the following confirmed conclusions are:

1. In Burqin region, the maximum concentration founded was 207,4 Bq/m^3, that very exceeds the assigned limit set by WHO (100 $Bq./m^3$) . This value is reported for limited cases. Other concentration levels are within the allowed concentration level.

   The effective dose for that is 5.2 mSv/y and corresponding value of exhalation rate is 27.5 milli $Bq./m^2hr$, the Minimum Concentration is 5 $Bq./m^3$, with effective dose of 0.13 mSv/y and exhalation rate of 0.67 milli $Bq./m^2hr$. The obtained results are within the safe range that set by WHO.

   In general, the average concentration over Burqin suburb is 32.4 $Bq./m^3$ with an average annual effective dose of 0.82 mSv/y and exhalation rate of 4.3 milli $Bq./m^2hr$.

2. In Al-Hashimya suburb , the results were less than Burqin suburb .

   In general, the maximum radon concentration levels were founded to be 163.8 Bq/m^3, with corresponding maximum annual effective dose of 4.13 mSv/y and maximum exhalation rate of 21.7 milli $Bq./m^2hr$. Besides, the minimum concentration is 1.6 $Bq./m^3$ with a corresponding effective dose of 0.04 mSv/y and minimum exhalation rate of 0.21 milli $Bq./m^2hr$.

   The average radon concentration levels all over Al-Hashimya region is 26.8 $Bq./m^3$ with an effective dose of 0.68 mSv/y and exhalation rate of 3.6 milli $Bq./m^2hr$

3. The maximum radon concentration levels in all regions is 207.4 Bq/m^3. That can result in an annual effective dose of 5.2 mSv/y and exhalation rate of 27.5 milli $Bq./m^2hr$, while the minimum concentration levels of 1.6 Bq/m^3 can result in an effective dose of 0.04 mSv/y and exhalation rate of 0.21 milli $Bq./m^2hr$. The overall average radon concentration level is 29.6 $Bq./m^3$ with an average annual effective dose of 0.75 mSv/y and exhalation rate of 3.9 milli $Bq./m^2hr$.
4. High concentrations were obtained in the kitchens and bed rooms, despite the presence of ventilation holes in most of them, but it seems that there are internal causes for this high concentration, which may be due to the contents of those kitchens materials such as granite materials.

5. Just 3.3 % of samples exceeded the concentration of 150 Bq/m^3, which was determined by the Environmental Protection Agency(EPA) and 5.5% of samples exceeded the concentration of 100 Bq/m^3, which was determined by the (WHO) .In conclusion, investigated areas in general are classified as safe areas from radon gas radiation pollution and its hazardous effects on human beings, but we should not forget to follow up other precautions like taking continuous care of ventilation measures from time to time .

4.2: Recommendations

The risk can be reduced effectively based on procedures that include optimization and evaluation of available control techniques. In general, simple remedial measures should be considered for buildings with radon progeny concentrations of more than 100 Bq/m^3 as assigned by WHO.

With a strong recommendation to reduce radon concentration levels to the world wide recommended values .

Radon reduction techniques that can be used in all home types, include multi-methods as the natural ventilation that recommended in all homes. This can be achieved by continuously opening windows, doors and available the lower floor vents. By doing that ,the ventilation in home can result in reduced radon levels.

However, once windows, doors and vents are closed, radon concentration levels, most often, will be increased to its previous levels. Natural ventilation in any home type should normally be regarded as only a temporary radon reduction approach, because of the following disadvantages:

1. loss of conditioned air and related discomfort.

2. greatly high costs of conditioning additional outside air.

3. security concerns.

Therefore, there should be other methods to reducing radon gas, like sealing and heat recovery ventilation.

Sealing cracks and other openings in the foundation is a basic part of most approaches to radon reduction. Sealing the cracks limits the flow of radon into home and also reduces the loss of conditioned air, that measures are not sufficient, as it was difficult to identify and permanently seal the places where radon is entering.

A Heat Recovery Ventilator (HRV), also called an air-to-air heat exchanger, can be installed to increase ventilation, which will help reduce the radon levels in the home. An HRV will increase ventilation by introducing outdoor air while using the heated or cooled air being exhausted to warm or cool the incoming air. HRVs can be designed to ventilate all or part of the home, although they are more effective in reducing radon levels when used to ventilate only the basement. If properly balanced and maintained, they ensure a constant degree of ventilation throughout the year. HRVs also can improve air quality in homes that have other indoor pollutants.

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Appendix

Table A

Al-Hashimya						
No.	**Dosimeter Sample No.**	**Type Room**	**Floor**	**C_{Rn} Bq/m^3**	**H_E Sv/y**	**Ex. Rate Bq/m^{2}hr**
1	75	Store	1	61.4	0.00155	0.008151988
2	27	Store	1	22.9	0.00058	0.003038227
3	51	Store	1	28.6	0.00072	0.0038022
4	2	Store	1	23.1	0.00058	0.003064724
5	1	Store	1	33.8	0.00085	0.004482269
6	100	Store	1	17.2	0.00043	0.002278671
7	89	Guest	2	7.9	0.00020	0.001055431
8	9	Guest	3	17.7	0.00045	0.002349327
9	45	Guest	1	25.0	0.00063	0.003320853
10	74	Guest	1	20.5	0.00052	0.002715857
11	56	Guest	2	5.5	0.00014	0.000724229
12	44	Living	2	19.2	0.00048	0.002552464
13	77	sleep	1	28.1	0.00071	0.003727128
14	20	Guest	3	7.8	0.00020	0.001042183
15	28	Guest	2	13.5	0.00034	0.001792907
16	22	Guest	4	1.6	0.00004	0.000211969
17	15	Guest	4	21.8	0.00055	0.002888082
18	66	Living	3	7.5	0.00019	0.001002438
19	29	Living	2	12.9	0.00032	0.001709003
20	63	Store	1	20.4	0.00051	0.002707025
21	16	Guest	3	18.0	0.00045	0.002393487
22	31	Store	1	16.1	0.00041	0.002132942
23	59	Store	1	15.8	0.00040	0.002102029
24	41	Store	1	11.6	0.00029	0.001541194
25	81	Store	1	8.1	0.00021	0.001081927
26	35	Store	1	11.0	0.00028	0.001461705

27	61	Store	1	5.9	0.00015	0.000781637
28	23	Guest	2	1.6	0.00004	0.000207553
29	68	Guest	2	15.4	0.00039	0.002044621
30	21	sleep	2	14.2	0.00036	0.001881228
31	97	sleep	2	5.5	0.00014	0.000724229
32	57	sleep	2	12.6	0.00032	0.001669259
33	26	Living	2	19.2	0.00048	0.002543632
34	98	Living	2	28.0	0.00071	0.00371388
35	75	Store	1	40.5	0.00102	0.005378722
36	47	Store	1	107.6	0.00272	0.014290268
37	39	Kitchen	2	163.8	0.00413	0.021744523
38	7	Kitchen	2	107.0	0.00270	0.014210779
39	33	Living	3	8.8	0.00022	0.001170247
40	4	Living	3	8.8	0.00022	0.001174664
41	34	Guest	1	37.8	0.00095	0.005016608
42	54	sleep	1	18.7	0.00047	0.002481808
43	36	sleep	2	58.3	0.00147	0.007736882
44	70	Store	1	30.2	0.00076	0.004009754
45	37	Store	1	34.1	0.00086	0.004522013
46	42	Store	1	37.1	0.00094	0.004928288

Table A : Data Al-Hashimya

Table B

Burqin						
No.	**Dosimeter Sample No.**	**Type Room**	**Floor**	**C_{Rn} Bq/m^3**	**H_E Sv/y**	**Ex. Rate Bq/m^{2}hr**
1	59	Guest	1	17.7	0.00045	0.002353743
2	60	Guest	1	13.7	0.00035	0.001819404
3	25	Kitchen	2	10.7	0.00027	0.001421961
4	5	Kitchen	2	10.1	0.00025	0.001338057
5	98	Store	1	23.2	0.00059	0.003082388
6	84	Store	1	5.0	0.00013	0.00066682
7	30	Store	1	10.1	0.00026	0.001342473
8	93	Store	1	11.7	0.00030	0.001558858
9	82	Store	1	12.2	0.00031	0.001620682
10	12	Living	2	24.1	0.00061	0.003201621
11	32	Living	2	13.2	0.00033	0.001748747
12	3	sleep	2	26.5	0.00067	0.003515159
13	22	Kitchen	2	25.0	0.00063	0.003320853
14	95	Store	1	207.4	0.00523	0.027542768
15	6	Store	1	14.3	0.00036	0.001903308
16	61	Living	2	95.0	0.00240	0.012616593
17	51	Kitchen	2	91.9	0.00232	0.012205902
18	53	sleep	2	84.9	0.00214	0.01127412
19	87	Living	3	20.6	0.00052	0.002733522
20	66	Living	3	18.2	0.00046	0.002415567
21	10	Kitchen	3	32.0	0.00081	0.004252635
22	24	Kitchen	3	28.2	0.00071	0.003744792
23	1	Guest	3	7.2	0.00018	0.000958278
24	23	Guest	3	15.3	0.00039	0.002026957
25	62	Guest	3	11.9	0.00030	0.001580938
26	57	sleep	3	24.4	0.00062	0.003241365
27	40	sleep	3	17.7	0.00045	0.002349327

28	8	Living	2	72.7	0.00184	0.009657854
29	23	Living	1	15.1	0.00038	0.002000461
30	64	Living	1	10.5	0.00027	0.001395465
31	11	Guest	4	14.0	0.00035	0.001863564
32	88	Guest	3	18.1	0.00046	0.002397903
33	13	Guest	3	13.7	0.00035	0.001819404
34	53	Guest	2	8.8	0.00022	0.001165831
35	14	Living	3	16.2	0.00041	0.002150606
36	18	sleep	3	15.0	0.00038	0.001996045
37	21	sleep	3	19.2	0.00048	0.002543632
38	86	Kitchen	4	10.2	0.00026	0.001355721
39	19	Kitchen	3	24.1	0.00061	0.003197204
40	99	Guest	3	31.3	0.00079	0.004155483
41	40	Guest	2	37.9	0.00096	0.005038688
42	25	Guest	2	77.8	0.00196	0.010324674
43	17	sleep	3	17.9	0.00045	0.002371407
44	27	Store	1	167.5	0.00423	0.022239118
45	38	Guest	3	14.8	0.00037	0.001969549

Table B : Data Burqin

ملخص الرســـــالة

في هذه الدراسة ، تم تحديد مستويات تركيز غاز الرادون -٢٢٢ الداخلية (C_{Rn}) ، والجرعة السنوية الفعالة (H_E) ومعدل الزفير (E_x) في بعض مساكن ضاحيتي الهاشمية وبرقين في محافظة جنين في فلسطين.

تم استخدام كاشف المسار النووي للحالة الصلبة (SSNTD) من النوع CR-39.

تم العثور على مستويات تراكيز غاز الرادون في الهاشمية والتي تراوحت من (١,٦ إلى ١٦٣.٨) بيكريل/م^{٣}، بمعدل ٢٦,٨ بيكريل / م^{٣} .

تراوحت التراكيز في ضاحية برقين من (٥ إلى ٢٠٧,٤) بيكريل / م^{٣} بمعدل ٣٢,٤ بيكريل / م ^{٣}.

متوسط قيم الجرعة السنوية الفعالة في ضاحيتي الهاشمية وبرقين ٠,٦٨ وَ ٠,٨٢ (ملي سيفرت / سنة) لكل منهما على التوالي.

تفاوت معدل الزفير في ضاحية الهاشمية من ٠,٢ إلى ٢١,٧ (ملي بيكريل / م^{٢} ساعة) وبمعدل ٣,٦ (ملي بيكريل / م ٢ ساعة) .

وتفاوت معد الزفير في ضاحية برقين من ٠,٦٧ إلى ٢٧,٥ (ملي بيكريل / م^{٢} ساعة) بمعدل ٤,٣ (ميلي بكريل / م^{٢}ساعة).