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Indoor Radon-222 Concentration Levels Measurements in Sourif Dwellings During the Summer and Autumn Seasons of the Year 2009

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1431 / 2010

Dedication

To my mother and father as they are my great supporter

and so much more……

To my lovely family that just never stopped giving me a help…

To my lovely fiancé "Mahmud"

To my supervisor Prof. Dr. M. Abu-Samreh….

To all my teachers and friends….

With all my love

Sana Azmi Ibrahim Abu Fara

Declaration:

I will certify that this thesis submitted for the Master degree in physics is the result of my own research, except where otherwise acknowledged. This thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed: …………………

Sana Azmi Ibrahim AbuFara

Date:………………………

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Thanks to Allah, the most merciful the most compassionate, who granted me the power and the ability to finish this work.

I would like to express all my deepest thanks and gratitude to my supervisor, Prof. Dr. Mohammd Abu-Samreh for his kindness, politeness, patience, encouragement and guidance through the work.

Many thanks go to my nice parents, to my fiancé, to my brothers and to my sisters for their encouragements and support.

Thanks are extended to Dr. Khaleel Dabayneh from Hebron University for providing me with detectors.

So many thanks go to my friends and doctors their support. Special sincere thanks and gratitude's to homeowners and inhabitants who granted me the opportunity to complete this study, by allowing me to distribute the detectors in their flats and homes.

Abstract

In this study, we are basically aimed on investigating indoor and outdoor radon-222 concentration levels in some dwellings chosen randomly from six regions in Sourif city during time period between August 1 of the 2009 to January 31 of the year 2010 using Solid State Nuclear Tracks (SSNTDs) or (CR-39 detectors). The results showed that the indoor radon-222 concentration levels vary from 6.29 to 857.05 Bq/m^3, with an average value of 73.03 Bq/m^3; while the outdoor concentration levels were found to vary between 6.12 to 89.38 Bq/m^3, with an average value of 33.57 Bq/m^3. The effective doses equivalents vary from 0.11 to 14.83 mSv/y, respectively.

Higher average values of indoor radon concentration levels were found in bathrooms (104.96 Bq/m^3) and storages (103 Bq/m^3); while relatively lower values of 78.24 and 64.6 Bq/m^3 were detected in bedrooms and kitchens respectively. The lowest average indoor radon concentration levels of 54.77 Bq/m^3 were detected in living rooms.

The concentration levels were found to be higher in lower floors (the first floor) than that of higher floors (second floor). Moreover, concentration levels are found to be higher in old buildings than the newly constructed ones.

The indoor radon concentration levels were found to vary from location to another. A noticeable differences between the minimum and maximum concentration levels results in each region had been detected. These variations are mainly due to the ventilation, geological characteristics of soil, and the types of raw building materials, are also the age of dwellings.

The outdoor radon concentration levels were found to be lower than the indoor concentration levels. This is because the outdoor dosimeters were placed in an open places where air can exchange easily between the dosimeter and the outside. That is, the radon gas can diffuse easily with the atmosphere and the possibility for being trapped is very low.

الخلاصة:

قياس تراكيز غاز الرادون(^{222}Rn) في مساكن بلدة صوريف في فصلي الصيف والخريف لعام 2009.

إن الفكرةَ الرئيسيةَ لهذه الدراسة أن نتحرى تركيز غاز الرادون(^{222}Rn) الداخلي والخارجي في بعض مساكن بلدة صوريف والتي اختيرت بشكل عشوائي في ستة مناطق مختلفة, من شهر أب لعام 2009 إلى شهر كانون الثاني لعام 2010, وذلك باستخدام كواشف الحالة الصلبة للمسارات النووية (SSNTDs) والمعروف تجاريا باسم (CR-39). أوضحت نتائج هذه الدراسة أن تركيز غاز الرادون داخل هذه البيوت يتفاوت من 6.29 بيكرل/م^3 إلى 857.05 بيكرل/م^3 , بقيمة متوسطة 73.03 بيكرل/م^3. بينما تركيز الرادون في الهواء الطلق يتفاوت بين 6.12 إلى 89.38 بيكرل/م^3, بقيمة متوسطة 33.57 بيكرل/م^3. وكذلك بينت الدراسة أن التركيز مكافئ جرعة سنوي يتراوح بين 0.11 مللي سيفرت /سنة و14.83 مللي سيفرت/سنة, على التوالي.

القيمة العليا لمتوسط تركيز غاز الرادون داخل البيوت وجدت في الحمامات وكانت 104.96 بيكرل/م^3، والمخازن 103 بيكرل/م^3, بينما سجلت قيم أقل نسبيا في غرف النوم والمطابخ حيث وجد أن معدل التراكيز في غرفة النوم 78.24 بيكرل/م^3 وفي المطابخ 64.6 بيكرل/م^3 . أما أقل قيمة متوسطة فسجلت في غرف الجلوس; حيث سجلت 54.77 بيكرل/م^3.

دلت هذه الدراسة أن تركيز الرادون في الطوابق الأرضية و البنايات القديمة كانت أعلى من الطوابق المرتفعة عن الأرض والبنايات المبنية حديثاً. إن اختلاف النّتائِجِ بين القيم الدنيا والقصوى في هذه المناطق, قد يرجع لعدة أسباب منها :الخصائص الجيولوجية للتربة, و نسبة التهوية للبيوت, و أنواع المواد الإنشائية الخام المستخدمة في البيوت, و عمر البنايات, و عدد الطوابق المكونة منها هذه البيوت.

من خلال الدراسة تبين أن مستويات تركيز الرادون في الهواء الطلق أقل من مستويات التركيز للغاز داخل البيوت ؛ ويعزى ذلك إلى أن الكواشف في الهواء الطلق وضعت في أماكن مفتوحة يسمح بتبادل الهواء بين الكواشف والهواء الخارجي بسهولة.

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Definitions:

Most of definitions listed below are taken from the following references.

- (http://www.jplabs.com/html/units_of_radiation.HTM.(3-11-2009);
- http://www.rcs.k12.va.us/chemistrynhs/advanced/01_adv_atomic/advanced_atomic.htm (22-4-2009).

- **Absorbed dose**: The amount of energy of an ionizing radiation absorbed per unit mass of material. The standard unit for absorbed dose is the gray (Gy) is defined as 1J of energy absorbed per kg of medium.

- **Activity:** Activity of a radioactive substance is the number of decays per time.
- **Alpha particle:** The nucleus of helium atom that consists of 2proton, 2neutron. Alpha particles are energetic, positively charged particles, lose energy rapidly in matter and do not penetrate very far.
- **Background radiation it refers to:**

  1. The general level of natural and man-made radiation's against which a particular added radiation component has to be considered, when discussing radiation levels and effect. .

  2. It spurious readings due to the 'noise' characteristic of the instrument and its power supplies, and to the presence of local radioactive contamination etc, when discussing radiation measurement techniques.

- **Becquere**l (Bq): A unit of **activity** of a radioactive source or 1 Bq = 1 decay/sec.
- **Beta Particles:** Negatively charged particles emitted from an atomic nucleus having a mass and charge equal to that of an electron. Because of their light mass and single charge, beta particles can penetrate more deeply than alpha particles, and a few millimeters of aluminum will stop most beta particles.
- **Cosmic rays:** High energy charged particles traveling through interstellar space at nearly the velocity of light.
- **Curie** (Ci): A unit of **activity** of a radioactive source, where 1 Curie = 3.7×10^{10} Bq.

- **Decay:** The disintegration of the nucleus of an unstable atom by spontaneous fission by the spontaneous emission of an alpha particle or beta particle by electron capture.
- **Electromagnetic Radiation:** Radiation that travels through vacuous space at the speed of light and propagates by the interplay of oscillating electric and magnetic fields. This radiation has a wavelength and a frequency and transports energy.
- **Electron volt (eV):** It is a unit of energy which represents the amount of kinetic energy which gained by an electron as it passes through a potential difference of 1 volt. It is equivalent to 1.662×10^{-19} joules.
- **Equivalent dose***:* The dose multiplied by a radiation-weighting factor. The unit of equivalent dose is sievert (Sv).
- **Gamma rays:** Short wavelength electromagnetic radiation higher in frequency and energy than visible and ultraviolet light. Gamma rays are emitted from the nucleus of an atom. These high energy photons are much more penetrating than alpha and beta particles.
- **Gray** (Gy): A unit of absorbed dose of ionizing radiation, and is measured in 1 Joule/kg, or 6.25×10^{12} MeV/kg.
- **Half-life time ($T_{1/2}$)** : The time in which half the original unstable nuclei have to decay and half nuclei still survive. $T_{\frac{1}{2}} = \frac{\log 2}{\lambda} = \frac{0.693}{\lambda}$, where λ is the decay constant (s^{-1}).
- **Ionizing radiation**: Any electromagnetic or particulate radiation capable of producing ionization in matter. Examples of ionizing radiation include alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions..
- **Isotopes:** Atoms having the same numbers of protons in their nuclei, but different numbers of neutrons.
- **Non ionizing radiation**: Electromagnetic or particulate radiation that lacks sufficient energy to remove electrons from the outer shells of atoms. This definition excludes non-ionizing radiation, such as radio- or microwaves, or visible, infrared, or ultraviolet light
- **Rad**: The absorbed dose of ionizing radiation which is equal to 10 milligray (mGy).
- **Radiation**: Energy emitted in the form of waves (light) or particles (photons).

- **Radioactivity**: The property possessed by some atomic nuclei of disintegrating spontaneously, with loss of energy through emission of a charged particle and/or gamma-radiation.
- **Radioactivity natural:** The radioactivity of natural occurring materials, e.g. uranium, thorium, radium, lead, potassium, carbon, hydrogen.
- **Radon**: A radioactive inert gaseous element of natural origin. It is estimated to cause about 53% of the total average radiation exposure.
- **Rem(Roentgen equivalent man):** The unit of effective radiation dose absorbed by tissue, being the product of the dose in rads and the quality factor. The rem is being replaced by the SI unit, the Sievert (Sv), equal to 100 rem.
- **Roentgen**: A unit of exposure to radiation based on the capacity to cause ionization. It is equal to 2.58 x 10^{-4} Coulomb per kg(C/kg) in air. Generally an exposure of 1 Roentgen will result in an absorbed dose in tissue of about 1 Rad.
- **Roentgen (rent-gen):** A basic unit of measurement of the ionization produced in air by gamma or x-rays. One roentgen (R) is exposure to gamma or x-rays that will produce one electrostatic unit of charge in one cubic centimeter of dry air. One thousand milliroentgen (1,000 mR)= 1R.
- **Sievert** (Sv): Dose equivalent; dimensionally J/kg, but calculated as the product of the physical absorbed dose in Gy and the Relative Biological Effectiveness.

  Sv = 100 rem (ICRP, 1990).

Abbreviations:

AM	Arithmetic mean
Bq	Becquerel
Bq/m^3	Becquerels per cubic meter
CEC	Country's European Common
CF	Calibration factor
Ci	Curie
cm	Centimeters
C_o	Radon concentration in calibration chamber
C_{Rn}	Radon concentration levels
decay/sec	decay per second
E_{AEDE}	Annual radon effective dose equivalent
EER	Equilibrium equivalent concentration of radon unit
EM	Electromagnetic radiations
EPA	The Environmental Protection Agency
f	Field view
Fig.	Figure
g/ℓ	Gram per liter
GM	Geometric mean
Gy	Gray
h	hour
ICRP	The International Commission on Radiation Protection
J/kg	Joule per Kilogram
kBq/m^3	kilo Becquerels per cubic meter
keV	kilo electron volt
kg/m^3	kilogram per cubic meter
m	Meter
Max	Maximum
MeV	Million electron volt
mGy	Milligray
Min	Minimum

mm	millimeter
mSv/y	milli sievert per year
N	Number of collected detectors
n	the number of field views
NaOH	Sodium hydroxide
No.	Number
^{o}C	Celsius degree
PADC	Polyallyl Diglycol Carbonate
pCi	Picocuries
pCi/ ℓ	Picocuries per liter of air
pp.	page to page
R	Roentgen
REM	Roentgen equivalent man
REP	Roentgen equivalent physical
SSNTDs	Solid State Nuclear Track Detectors
Sv	Sievert
t	exposure time of distributed detectors
t_o	exposure time of detector in radon chamber
T_s	sampling time in hours
WHO	the World Health Organization
WL	working-Level
WLM	working Level-Month
X_i	the number of tracks in the field view i
Z	atomic number
α	alpha particle
β	beta particle
γ	gamma ray
λ	decay constant
ρ	density of nuclear tracks
ρ_o	density of nuclear tracks measured after its calibration

Chapter One

Introduction and Radiation Background

Chapter One

Introduction and Radiation Background

1.1 Introduction

Radiation is the energy is released as particles or rays, produced through radiation processes in atomic transitions, accelerating charged particles, and radioactive processes from radioactive nuclides. All radiations are either resulted from naturally occurring resources such as cosmic rays, natural radioactivity particles produced during the spontaneous decay of natural radioactive substances and natural radioactivity in our bodies, or manmade resources (artificial) such as radiation produced by artificially radioactive decay processes, X-rays, nuclear weapons, nuclear technology, etc (James, 1995).

Radiations are found in Earth's surface, atmosphere, and in the Earth crust in bedrocks. A summary of the global background of various radiations sources is illustrated in Fig. (1.1)(http://www.rcs.k12.va.us/chemistrynhs/advanced/01_adv_atomic/advanced_atomic.htm, 22-4-2009)

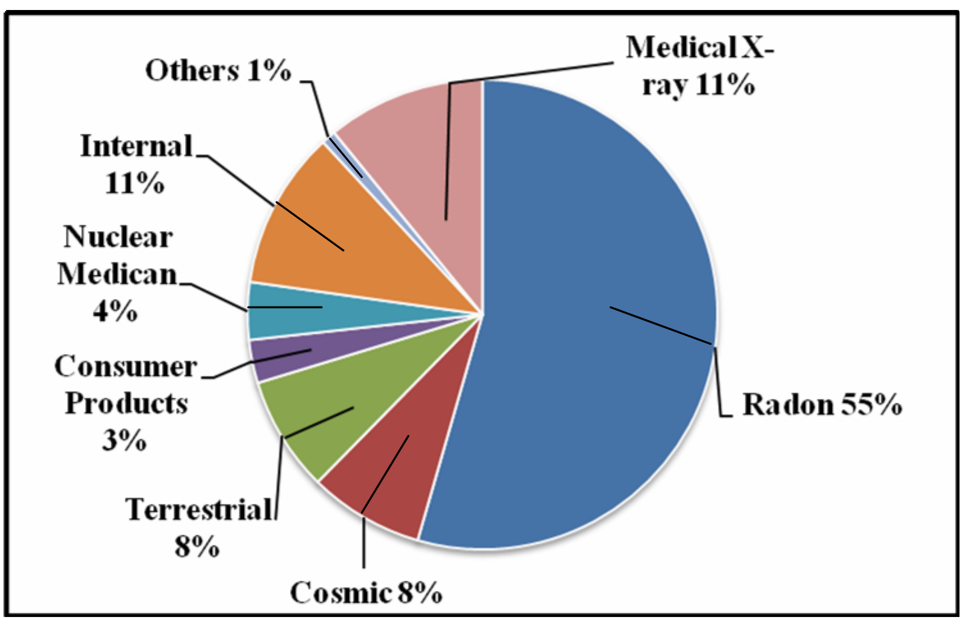

Figure 1.1: Sources of global background radiation worldwide (UNSCEAR, 2001).

Radiations are classified into electromagnetic (EM) radiations and charged subatomic particles such protons and electrons. Besides, they are also classified into ionized and non ionized radiations.

The non ionized radiation is referred to that type of radiation that does not carry enough energy per quanta to ionize atoms or molecules. More specifically, it refers to the lower energy forms of EM Radiation spectrum (i.e., radio waves, microwaves, infrared light, and visible light). On the contrary, the ionized radiation (subatomic particles or electromagnetic) possesses enough energy to detach electrons from atoms or molecules and leaving behind an ionized atom or molecule. Ionized radiations interact with matter through several radiation mechanisms, among: Bremsstrahlung, ionization, pair production, pair annihilation, electron capture, and internal conversion processes. A summary of the ionized radiation interaction with matter is exhibited in Fig.(1.2) (www.osha.gov/SLTC/radiationionizing/introtoionizing/ionizinghandout.html, 6-3-2010).

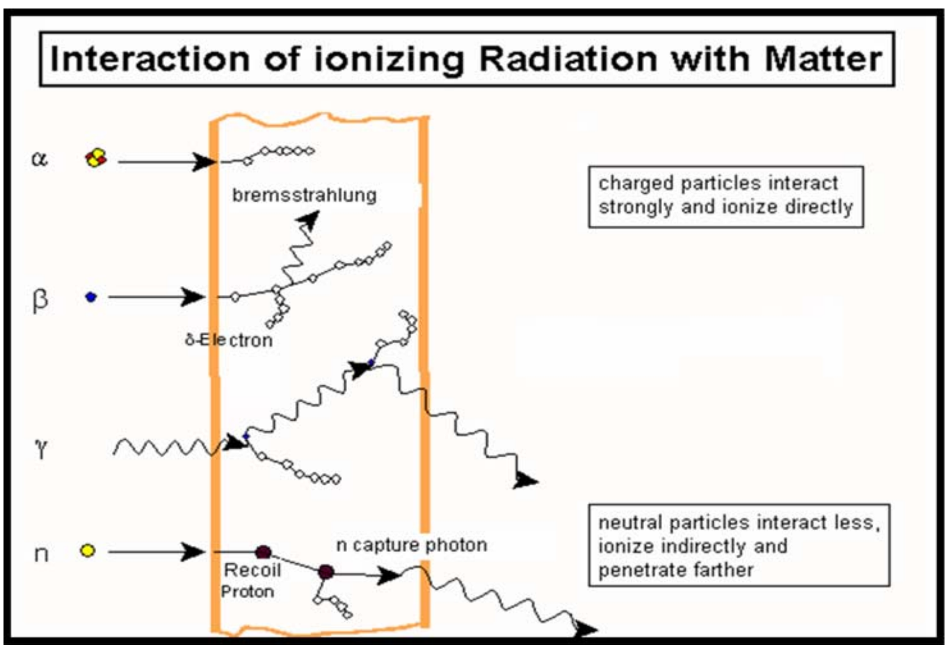

Figure 1.2: Interaction processes of ionizing radiation with matter. (www.osha.gov/SLTC/radiationionizing/introtoionizing/ionizinghandout.html, 6-3-2010).

In this study, we are concerned basically in investigating the effect of ionizing radiation produced in one of the natural decay processes during the uranium decay series, the radon decay process. Accordingly, we shall discuss the natural radioactive decay series that is relevant to the production of radon in more details in the next section.

1.2 Natural Radioactivity

Natural radioactivity are resulted in most heavy elements having atomic number (Z) greater than 83 and produce an ionized radiations in general. Besides, there are several natural radioactive isotopes with an atomic number less than 83 such as $^{40}_{19}K, ^{87}_{37}Rb, ^{152}_{62}Sm.$

There are three basic natural radioactive decay series and one artificial series. The three basic decay series are of uranium-238 (^{238}U), thorium-232 (^{232}Th) and uranium-235 (^{235}U) series (Mann, *et al.,* 1980; Green, *et al.,* 2009). Fig.(1.3) exhibit the various decay modes of ^{238}U, ^{235}U and ^{232}Th series, respectively. All radioactive series start from unstable nuclide such as uranium and follow several decay processes to reach the stable element of lead as shown in Fig. (1.3) (James, 1995).

^{238}U has a very long half-life, about 4.5×10^{10} years, but when it decays it produces atoms of much shorter half-life until, after about 20 stages, it becomes the stable lead isotope ^{206}Pb. One of these stages is the element radium which was the first radioactive isotope to be used for the treatment of disease. Another of the stages is radon, which appears in the atmosphere as a radioactive gas. In the morning when the air is very still, radon gas coming from the ground can accumulate in quite high concentrations in the air. There are usually about 106 radon atoms in each cubic meter of air (Bodgorsak, 2006).

Ionized radiations such as alpha, beta, and gamma, radiations are produced through cascade radioactive decay processes of a heavy element to become stable element (http://www.unscear.org/unscear/en/publications/2000_1.html, 22-1-2010). Other ionized radiations such as X-rays are produced by X-ray machines. Moreover, fast neutrons and photons are produced in nuclear facilities.

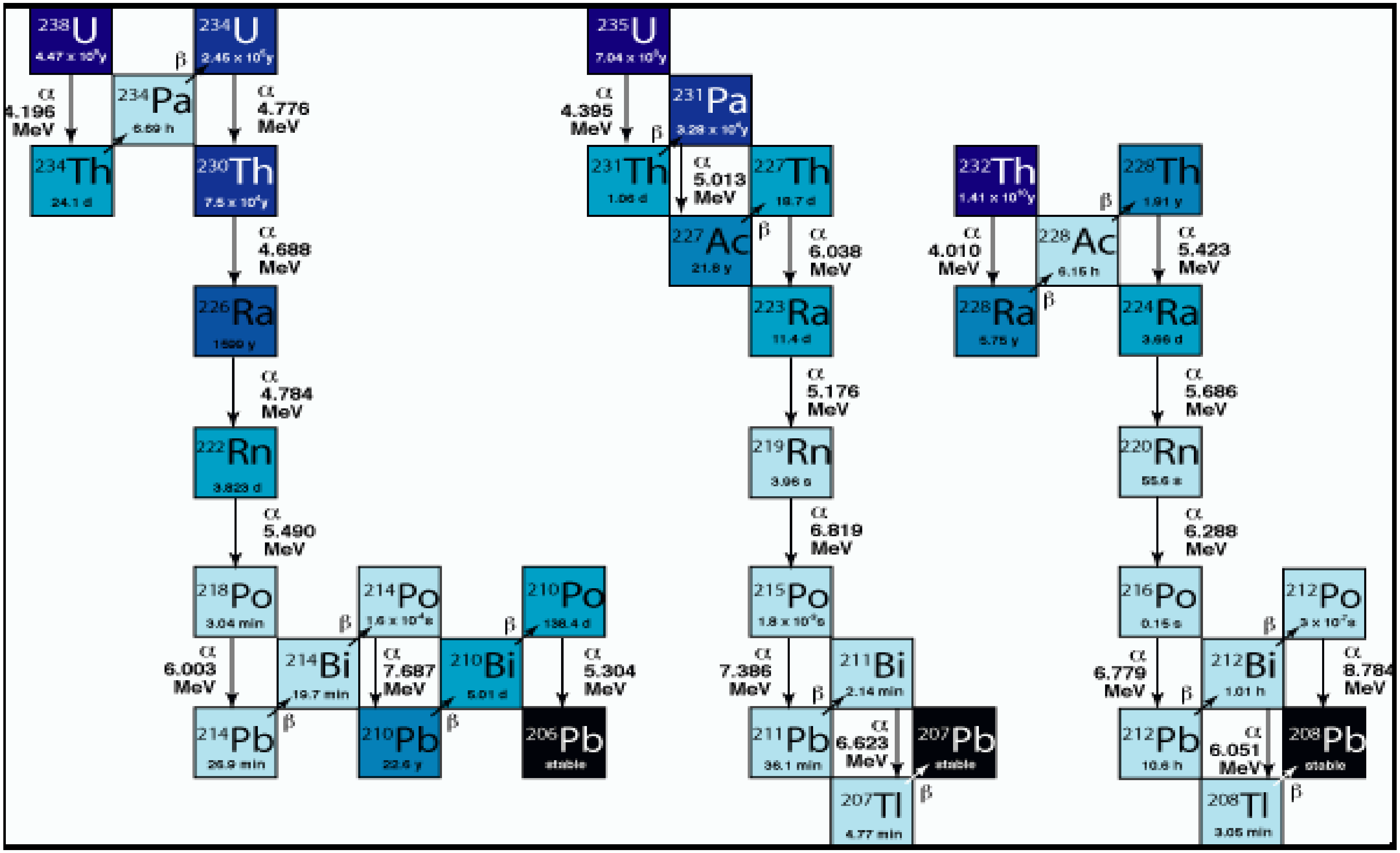

Figure 1.3: Illustration of the natural decay series of ^{238}U, ^{235}U and ^{232}Th.
http://www.rcs.k12.va.us/chemistrynhs/advanced/01_adv_atomic/advanced_atomic.htm (22-4-2009).

The alpha particles (α), the helium nucleus (^{4}He) that has two protons and two neutrons, are positively energetic particles having energy spectrum that vary between 4 and 9 MeV. Alpha particle, loses energy rapidly in matter and having very small penetration depth in materials.
The beta particle (β), electrons, is produced in the nucleus during its decay into a new nucleus. The beta particle has two species namely: the negative beta particle (β^-), or the electrons, and the positive beta particle (β^+), the positron. The beta radiation has a continuous range of energies that might vary from zero to a maximum value characteristic of the nuclide.
The gamma (γ) radiation is emitted after α or β decay and has a very high frequency with short wavelengths in the region of 3×10^{-11} m (of energy ~ 41 keV) to 3×10^{-13} m (of energy 4 MeV) (James, 1995) .

In this study, we are concerned mainly in investigating the radon-222 (^{222}Rn) concentration levels. Therefore, we shall focus on radiation emitted during the uranium natural decay series especially the radon decay modes and its progeny. Therefore, it is of great importance to discuss some aspects of radioactivity and the related radon properties and its decay mode (James, 1995).

1.2.1 Background of Radioactivity:

Natural radioactivity existed since the done of era. There are several radioactive isotopes which are present in the ground and in the atmosphere which contribute to what is called 'background radiation'. This background radiation is important as it is a source of interference when measurements of radioactivity are being made.

The major background of radiation is the natural radioactive elements. Uranium is one of the radioactive elements present in the ground and, as traces of uranium are found in most rocks, there is background radiation everywhere. There are variations between rocks; for example, granite contains a relatively high concentration of uranium so that cities which are built upon granite, have a relatively high background radiation (Bodgorsak, 2006).

The second contributor to the background radiation is the cosmic radiation which comes from the radiation absorbed by the atmosphere or deflected by the Earth's magnetic field. The final contributor is the man-made background radiation. This is the radiation which is emitted from isotopes which have escaped into the atmosphere either from atomic weapons, from the industrial uses of atomic energy, nuclear technology, X-rays in medicine and radioactive isotopes (James, 1995).

1.3 Units of Activity and Radioactivity

Radiation particles such as alpha, beta, and gamma, are produced during natural radioactivity decay processes (See Fig. (1.3)), and released into atmosphere, soil and water depending where the radioactive material might be located. The idea of a radioactive half-life was introduced to understand how quickly a radioactive isotope decays, but it does not tell you how much of the isotope is present. This is measured by the number of atoms which decay each second and is called the amount of activity. The activity units of radioactive source are:

(1) Becquerel (Bq). One becquerel (Bq) equals one disintegration per second.

(2) Curie (Ci). One Curie equals 3.7×10^{10} Bq.

For the quantities of radioisotopes used in diagnostic tests, curie is a rather large unit and the becquerel is a rather favourable small unit. For example, for a typical diagnostic dose of 10 mCi = 370 MBq (mega-becquerel) (http://www.jplabs.com/html/units_of_radiation.HTM. (3-11-2009)).

1.4 Radiation Dosimetry

All non-thermalized particles, with the practical exception of neutrinos, deposit their energy in the medium through which the propagate. The total energy deposited per unit mass (of the medium) is called the dose. Which is measured in units of Gray (Gy). The dose is generally referred to a flux of particles over a specified period of time (Basdevant, *et al.,* 2005).

Biological effects of radiation depend not only on the total energy deposited but also on the density of the energy deposit. The equivalent dose is therefore used to have a better estimation of biological damage caused by the disruption in cells due to ionization and the resultant breaking of molecular and chemical bonds. The most important risks involve mutations that can cause cancer. The unit of equivalent dose is the Sievert (Sv) (Bodgorsak, 2006).

In Table (1.1), we summarizes all typical contribution of various sources of radiation to the mean equivalent dose we receive annually (in the absence of a local nuclear event). The primary sources are cosmic rays, 0.26 mSv at sea level, and natural radioactivity, ~ 2 mSv. The α− and β−particles from natural activity are mostly confined to the material containing the radioactivity and are therefore not dangerous unless ingested. However, γ−rays are produced during the β-decays near the surface of materials radiates continually.

More important than the photon emitters is the α-emitting noble gas Radon produced in the uranium–thorium chains. The most energetic of the photons are the 1460 keV 40K and 2620 keV γ-rays. It diffuses out of the ground and building materials, generating an effective dose of~ 1−2mSv for building dwellers (Basdevant, *et al.,* 2005). This can be an order of magnitude smaller for people living outside and an order of magnitude higher in poorly ventilated buildings or in granite rock areas.

The effective dose derived from ingesting or inhaling radioactive materials (Table (1.1)) is difficult to estimate since it depends critically on where and for how long the body stores the particular material (Lehnert, 2007).

Table 1.1: Typical annual effective doses (Lehnert, 2007)

Source	Dose (mSv)
Cosmic radiation	200 μSv (20 mrem) over 1 year
Sea level	0.26
2000m above sea level	0.40
Air travel (per 1600 Km)	0.01
Natural radioactive materials(uranium in the ground)	300 μSv (30 mrem) over 1 year
Ground γ-rays	0.46
Air (radon)	2.0
Weapons test fallout	0.01
Dwelling (stone / brick / concrete) γ-rays	0.07
Food and drink	0.3
Television	00.10
Medical X-rays	0.40

1.5 The Radon Decay Modes

One type of radiations that attract scientists attention during the past six decades is the natural decay mode of radon. Radon and its progeny are produced during the natural radioactivity decay series (see Fig. (1.3)). Basically, radon has three main natural isotopes; namely, ^{222}Rn, a decay product of ^{238}U has a half-life of 3.825 days. Radon-220 (^{220}Rn), (known as thoron), it is produced in the decay series of ^{232}Th has a half-life of 55 seconds. Radon-219 (^{219}Rn), a decay product from the chain originating with ^{235}U has a half-life of about 3.96 seconds. Radon's isotopes ^{219}Rn, ^{220}Rn ^{222}Rn all emit alpha particles when they decay, with alpha energies of 6.8 MeV, 6.28 MeV, 5.48 MeV, respectively. The first two isotopes have little importance in terms of environmental impact; that is, the levels of their impact in nature are too small to be detected because of their half-lives are too short (Krane ,1988).

1.5.1 Physical and Chemical Properties of Radon:

Radon is an invisible gas, colorless, odorless, tasteless radioactive, gaseous material. It is also considers a noble (inactive) gas that does not combine chemically with any other elements or compounds in nature (Martinelli, 1993). Radon is moderately soluble in water and has a high solubility in organic liquids, with the exception of glycerine (Tommasino, 1995). Some chemical and physical properties of radon are reported in Table (1.2).

Table 1.2: Chemical and Physical properties of radon (NCRP, 1988).

Property	**Value**	
Boiling point (normal pressure)	$-61.8^{o}C$	
Density (normal temperature and pressure)	$9.96\ kg/m^3$	
Coefficient of solubility (g/ℓ) in ,at the water at atmospheric pressure temperature of :	**Temperature (^{o}C)**	**Coefficient (g/ℓ)**
	0	0.57
	20	0.250
	37	0.167
	100	0.106
Coefficient of solubility (g/ℓ) at atmospheric pressure and temperature of $18^{o}C$ in:	**Type of medium**	**Coefficient (g/ℓ)**
	Hexane	16.56
	Olive Oil	29.00
	Petroleum (liquid paraffin)	9.20

1.6 The Sources of the Indoor Radon Concentration

Radon concentrations in the environment has several sources. The first source is the exhalation of radon from the earth's crust and from the building materials form the main sources of this gas in the outdoor and indoor environments and dwellings. Radon infiltrates through conduits, cracks and micro fissures in the floor that are in contact with the soil (Arvela, *et al.,* 1988). The infiltration of radon gas (^{222}Rn) from soil has been identified as one of the main mechanisms influencing indoor radon levels in many buildings. It was reported that worldwide average of 60.4% of indoor radon comes from the ground and the surrounding soil of buildings (Ren, 2001).

The concentration of radon gas in ground gases is usually very high, of the order of tens of thousands of Bq/m^3. Therefore, even modest influxes can raise the indoor radon concentration substantially. The influx of radon from the soil is due to the outdoor–indoor pressure difference across the lower part of the structure of the house, and is the result of the coupling between the building and the soil (Nazaroff, and Nero, 1988).

The second source is the untreated groundwater where radon can be dissolved easily in water. Groundwater is affected by the composition of bedrock and soil. Thus, in areas with high concentrations of radionuclides in groundwater, the bedrock typically consists of granites which is generally rich with radon sources (Salonen, 1994; Salonen, and Huikuri, 2000; Lahermo, *et al.,* 2001). Waters containing radon are a major source of radiation in two ways: firstly, radon emanation from the source raises the concentrations in the air, hence increasing the dose by inhalation. Secondly, radon dissolved in water also contributes to the dose increase by ingestion (EPA, 1999).

The third source of radon and its progeny is the raw material used in building construction. The main construction materials that are found to serve as major sources of indoor radon pollution are granite, cement, stone and the ground itself (Dabayneh, 2008). Generally, radon concentration levels differs significantly from region to region according to the geographical type of soil and rocks, and depends on other parameters such as water resources used in buildings and natural gas used for cooking in the kitchen(Nazaroff, and Nero, 1988).

Fig.(1.4) illustrates the basic channels from which radon gas might be enter dwellings (Wilkening, *et al.,* 1972). Investigation had shown that the indoor radon concentrations are much greater than that of outdoor concentration levels. Also, radon concentration are found to be strongly dependent several factors among ventilation, soil and rock geographical types, water resources, etc….

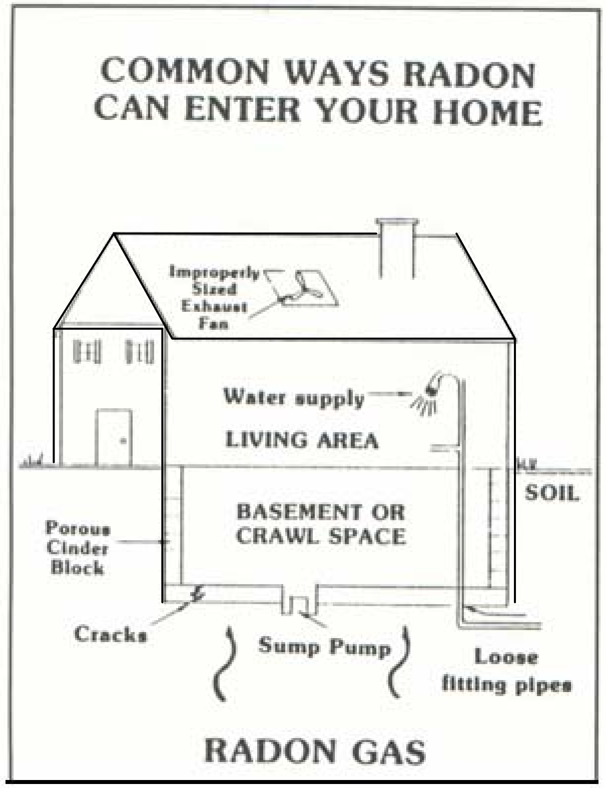

Figure 1.4: Sources of radon gas in dwellings (Wilkening, *et al.,* 1972).

1.7 The Radon Concentration Levels

As mentioned in section (1.6), there are many factors affecting the radon concentration levels and its progeny inside dwellings. Why the concentration levels of radon might be different in the same building? It was verified experimentally that the radon concentration levels vary in accordance to the building geographical location, building elevation (level of the houses), ventilation rate (Rahman, *et al.,* 2010). The radon levels are also significantly influenced by topography, house construction type, soil characteristics, weather, and even the life style of the people. In houses with higher concentrations, the main source of radon is the soil gas of ground (Pinza, *et al.*, 1997). Radon in soil gas depends on the radium content of the soil and the bedrock surrounding ground water wells. The physical characteristics of soil, the gas density and void fractions influence the transport of radon and its exhalation rate in the building atmosphere. Generally speaking, radon exhalation process is achieved by means of gas diffusion from building materials to rooms (Nazaroff, and Nero, 1988). Furthermore, the radon concentration levels were found to be different from one season to another where there is a noticeable seasonal variations of radon concentration levels for the same place. This is because of weather affected factors such as temperature, humidity, and rain (Nazaroff, and Nero, 1988; Subba Ramu, *et al.,* 1992).

Indoor radon concentration levels depend both on the intensity of the radon sources and on the degree of air exchange between the indoors and the outdoors (Nazaroff, and Nero, 1988). Hence, the measurement radon concentration levels should take into account all parameters that affect the judgment on whether the inspected environment is polluted by radon gas or not? (Subba Ramu, *et al.,* 1992).

Investigations should examine the dwellings construction material and building ventilation design with respect to windows and doors. Measurement procedures should take into account the variations occurring in the radon levels as a result of the seasonal changes (Subba Ramu, *et al.,* 1990).

1.7.1 Units of Radon Concentration Levels:

All of indoors and outdoors radon concentration levels measurements are expressed as the radon activity per unit volume. Accordingly, several units can be used to express the radon concentration levels, among:
(http://www.jplabs.com/html/units_of_radiation.HTM. (3-11-2009))

1) The Curie per liter: Ci/liter. Here, Curie is an activity unit which is defined as 37 billion disintegration per second. The most used unit is the picocuries (pCi) per liter of air (pCi/liter),
2) The SI unit which is defined as Becquerel (Bq) per cubic meter (Bq/m^3),
   Typically pCi/liter = 37 pCi/L = 37 Bq/m^3.
   Here the becquerel is an activity unit which is defined as disintegration per second.

3) Working levels (WL). A working level month (WLM) is defined as 170 hrs (2l.25 working days/month x 8 hrs/day) in a work place at one WL. Thus, exposure of 12 hour a day in the home at one WL, corresponds to approximately 26 working level months per year. Exposure rate is typically given in working level months per year (WLM/year)

$$1\ \text{WL} = 200\ \text{pCi/liter} = 7400\ \text{Bq/m}^3$$ (Tommasino, 1995) .

1.8 Radiations in the Environment

All types of radiations play an important and sometimes vital role in our daily life. Every day, each one of us is exposed to radiations that will have side effects on health and environment. Because of the enormous human activities in the field of radiations, scientists become more and more aware of the radiation impact on life parameters on our planet (Earth). The effects of radiations on living tissues have been studied and it was found that non ionized radiations effect is relatively negligible or too small to be detected. Instead of producing charged ions when passing through matter, EM radiations have sufficient energy also to produce excitation, a process which it's represents the movement of an electron to a higher energy state.
(http://www.osha.gov/SLTC/radiationionizing/introtoionizing/ionizinghandout.html.(6-3-2010)).

On the contrary, the ionized radiations were found to cause damages over their short path through tissue by giving up all its energy to the living cell. Worldwide, in late fifties of the past century, people recognized that radiations have a harmful impact on environment and humans. Accordingly, the World Health Organization (WHO) addressed radiation monitoring as a challenging issue and is of great importance for both human and environmental protections. A tremendous number of investigations had been performed to monitor radiations levels and backgrounds and their impact on our daily life. Consequently rapid and accurate methods had been developed (El-Bahi, 2004).

1.8.1 The Impact of Radon on the Public Health:

Most investigations had revealed that radiations have a direct impact on our health especially effects that produces health problems such as lung cancer, leukemia, eye illness, etc. One of particular interest is radon impact on human health (Lucie, 1989).

Radon is of a particular problem to the environment because it emerges from the decay series as a noble gas that can leave the surrounding rock and enter buildings along with atmospheric air. It acts like a pollutant source to atmospheric air and environment in general (Sonzogni, and Alejandro, 2008). There are three basic sources of radon presence in our environment. When radon gas exists in the environment, it can enter the human body through ingestion and inhalation. Exposure to radon and its progeny is confirmed to be associated with a potential increased risk of lung cancer (Henshaw, *et al.,* 1990; Lucie, 1989; EPA, 1999; WHO, 2001). Currently, radon is considered the main cause of about 15 percent of all lung cancers in the world according to the latest World Health Organization (WHO, 2001; WHO, 2009). Statistics from the Environmental Protection Agency (EPA) that the radon gas is found to be the second source after smoking in the United States of lung cancer. At the same time, radon is the main cause of lung cancer for non-smokers. Fig. (1.5) shows the radon health risk (EPA, 2002). If an alpha particle strikes the chromosomes in the cell, it can affect on DNA and induces mutations which may affect oncogenes and tumor suppressor genes, leading to impair cellular growth control (WHO, 2001). Furthermore, radon is also suspected to be a major factor of skin cancer (Turner, 1995).

A general social concern about health risks associated with this alpha-emitting nuclide, ingestion of radon dissolved in water which is suspected to cause tumors in internal organs, mainly in the stomach and increasing the risk of developing cancer has been grown up worldwide (EPA, 1999; Bonotto and Caprioglio, 2002).

The dangerous of radon gas is attributed to the fact that radon is an unstable element that can attach itself to dust or smoke particles for a few minutes and it can decay into daughters as well as to alpha particle. Inhalation of radon gas or its progeny will increase the exposure of the lung tissues to short-lived alpha emitting radionuclides. The alpha particles attach themselves to the lung cells and loose its energy to these cells. Thus, the presence of alpha particle in the lung will increase the risk of lung cancer (EPA, 1999).

As proven scientifically that radon is one of the sources of lung cancer, there is a serious concern worldwide to minimize the radon impact on our environment as well as in human health. International and national agencies were concerned with the environmental protection in countries that are categorized as places of high radon concentration levels, to guide its citizens about the seriousness of the rate gas. Therefore, the universal principle of radiological protection currently provided methods to reduce the radiation doses that people can be exposed to the lowest possible level, whether these doses are caused by exposure to radon or other radioactive sources (AL-Hilal, and Mouty, 1994).

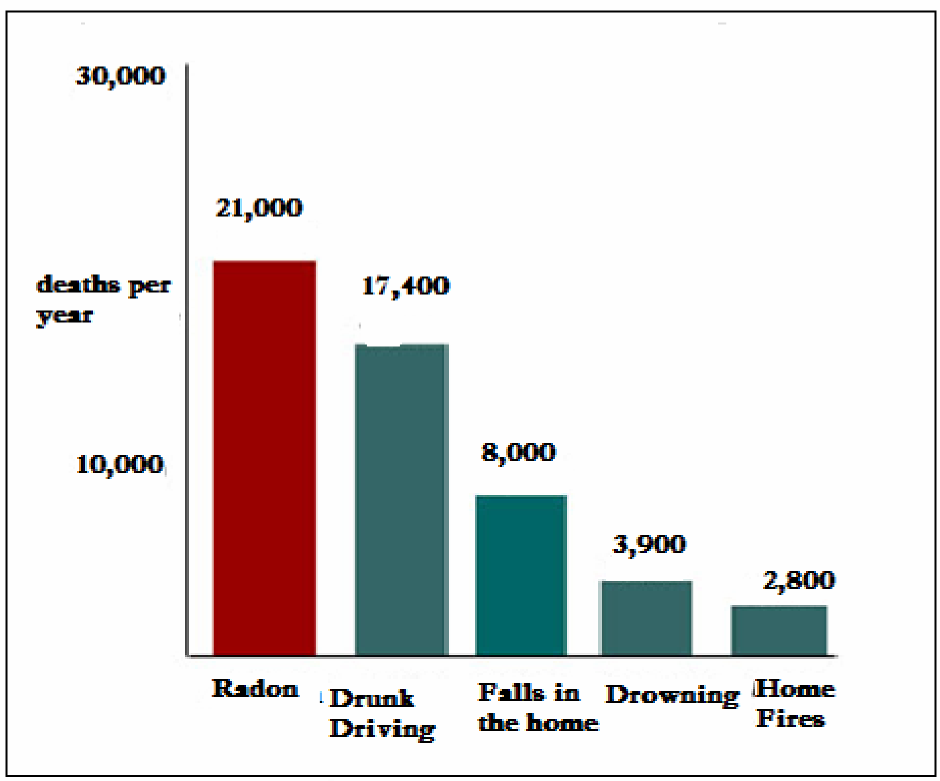

Figure 1.5: Illustration of radon impact on health risk (EPA, 2002).

1.8.2 Standard of Radiation Exposure Limits:

There is a serious concern worldwide investigate the indoor as well as the outdoor radon concentration levels. International and national agencies were concerned with the environmental protection in countries that are categorized as places of high radon concentration levels, to guide its citizens about the seriousness of the rate gas. Most countries have introduces standard levels that can not be exceeded and beyond that action should be taken for the public safety. The question, what are the allowed radon concentration levels beyond that harm to human health might be produced? The U.S. Environmental Protection Agency (EPA) a references level to recommended standard values of 150 Bq/m^3 or below for the radon concentration levels to be adapted as in USA, while an average effective dose of 7.5 mSv/y is considered as the level of interference. In Britain the concentration level references of interference is raised to 200 Bq/m^3, and in Germany to 250 Bq/m^3. Relatively speaking, there is no unique reference level in this context, to be adopted as the safest level in terms of protection of human health. As there is no unique safe level of exposure to radon, any level of exposure, no matter how small would it be, might constitute a measure of radon exposure risk, while less than these assigned values, risk is directly related to a low level of exposure to radiation. Table (1.3) summarizes the national and international limitations of the radon concentration levels (Frank, and Benton, 1979).

Table 1.3: National and international borders of the concentration of radon gas in homes.

Commission	The limits of recent house (Bq/m^3)	The limits of future house (Bq/m^3)	Date
The International Commission on Radiation Protection (ICRP)	400	200	applied in 1984
The Country's European common (CEC)	400	200	Proposal in 1989
World Health Organization (WHO)	800	200	applied in 1987
Sweden	800	150	applied in 1981
Britain	200	200	applied in 1990
Germany	250	250	Proposal in 1986
United States of America	150	150	applied in 1986

1.9 The Previous Studies in Palestine

There are about ten different independent research investigations that had been accomplished to measure radon concentration levels in Palestine. Table (1.4) summaries the radon concentration levels and the annual effective dose equivalent in some cities in Palestine.

Table 1.4: Level of radon concentration and the annual effective dose equivalent in Palestine.

References	Effective Dose equivalent(mSv/y)	Median of radon Concentration(Bq/m^3)	Study Region
Hassan, 1996	1.49	29.8	Hebron Univesity
Awawdeh, 2001	1.13 – 13	20-100	South Region of west bank
Abu-smreh, 2005	4.5 – 6.5	111 ± 63	Yatta city
Rasas ,*et al.,* 2005	---	38	Gaza Strip
Leghrouz ,*et al.,* 2006	---	91	Buildings of Hebron province
Dabayneh , 2006	0.62-12	34.1	Tarqumia girl schools
Dabayneh, Awawdeh, 2007	0.38-2.30	134	Dura city
Shehadeh, 2008	---	98 -124	Ramallah and Abu-Dies
Dweikat, 2004	4.94	98.8	Homes in old city of Nabluse
Dabayneh, Abu-Smreh	---	---	Schools in North Hebron, in press

1.10 Statement of the Problem

There has been a confirmation worldwide that lung cancer might be attributed to the in health radon gas. The fact that radon is found everywhere in the environment, will increase the possibility of environmental pollution and hence increase the lung cancer cases (Campi, *et al.,* 2004).

In this work, we are concerned mainly on investigating the annual indoor radon and outdoor concentration levels in Sourif dwellings, where no measurements have been made before. The work is a continuation of previous studies that had been performed in the Southern part of the West Bank (Awawdeh, 2001; Abu-Smreh, 2005; Dabayneh, 2006). The study is basically aims to examine and to report data on the radon concentration levels in this part of the West Bank.

1.11 Importance of the Study

Thus far, insufficient data concerning the radon concentration levels in Palestine are reported. This reflects the need of more studies and investigations to explore the radon concentration levels in Palestinian territories. Where different radon concentration levels will be expected due to the geological diversity of Palestine. We hope that this study shed light on the radon sources in the city especially the natural sources (soil, geographic nature) as well as the effects of construction materials and the building age. Solutions will be proposed and suggested on the basis of the obtained results in dwellings where there high concentrations of this gas were found. This might include warning people about the harm of the gas in their health and to improve their living status in a way the radon concentration levels should be kept within the assigned standard levels.

The obtained data will serve as a data baseline to test the radon pollution level of the inspected area as whole against the world assigned levels. This will be also helpful for exploring radiological danger of this radioactive gas on the city population if there is any.

We hope this study will pave the way to draw a radioactive radon map for the middle and southern areas of West Bank. We are looking forward having Palestinian assigned levels and standards that can be fully implemented in Palestinian territories as in many countries in this world.

1.12 Objectives

In this thesis, our main objective is to monitor the indoor radon as well as outdoor concentration levels in dwellings in one of the Palestinian cities, the Sourif city, where a few data have been reported (Awawdeh, 2001). Therefore, it is of great importance to give some information about dosimetry, radon and its impact on environment and humans.

1.13 Study Area

In this study, Sourif city and its surroundings See (Fig. (1.6)) will be chosen to serve as the study area to be investigated against radon concentration levels. Sourif is a small city, 18 km from Hebron old city, and is located in the North West part of Hebron. About 15 thousand inhabitants live in the city. The city is bordered to the east Beit Ummar and Safa, to the north Jab'a, and to the West 1949 Green line and to the south Kharas town. It is 537 meters above a sea level, with an average annual rainfall of about 660 mm, and an average temperature of 15.7 ^{o}C. The rate of relative humidity is about 60.7% (http://www.proxy.arij.org/vprofile/.html. (5-10-2009) . Fig. (1.6a) shows West Bank geographical map including the Sourif region (http://www.arij.org/paleye/hebron/heb_onh.gif.html,(23-3-2010). Sourif city separated geographical map showing the six regions the nuclear detectors were expected to be distributed, is shown in Fig. (1.6b).(http://www.arij.org/paleye/hebron/hebronh.gif.html,(23-3-2010))

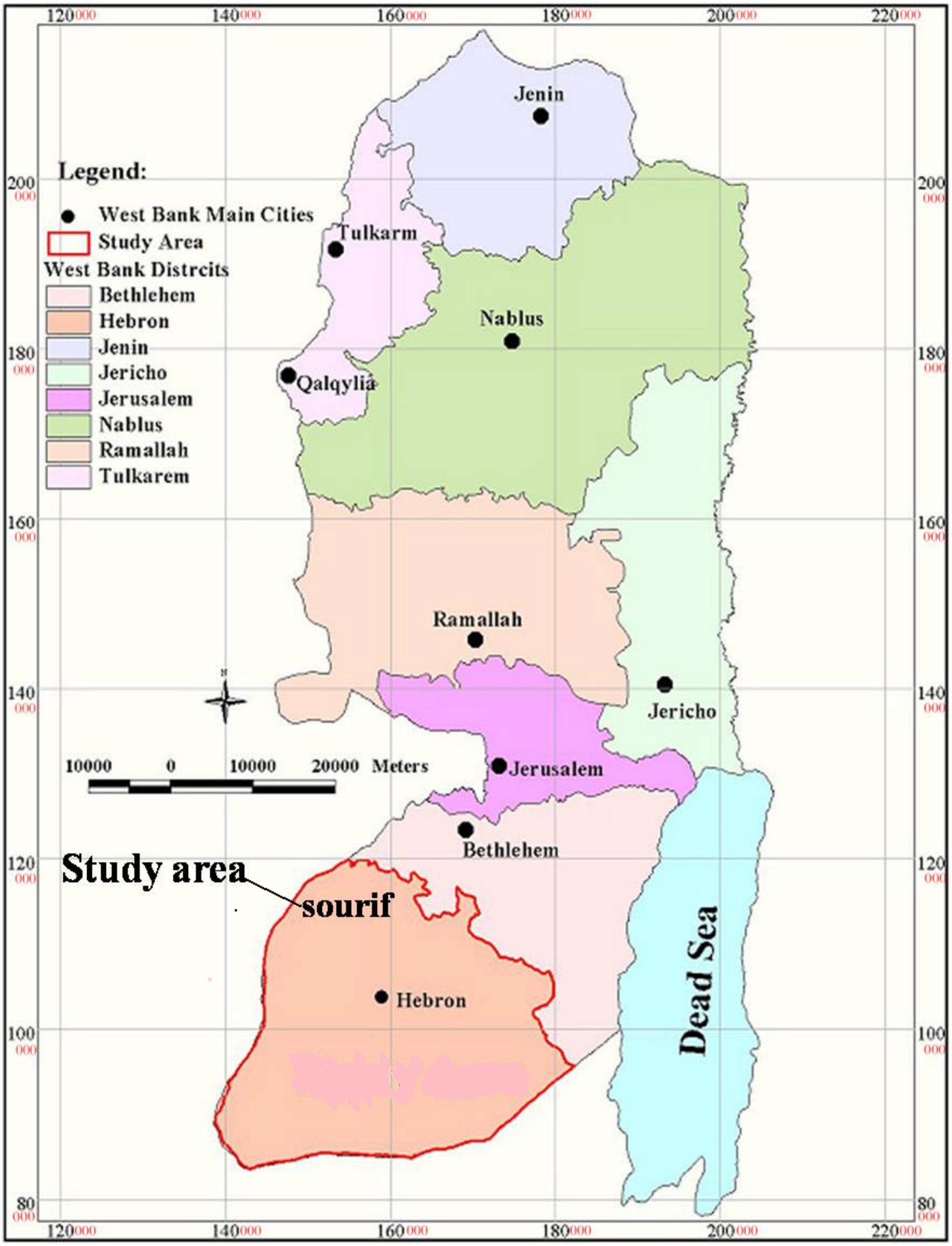

Figure 1.6a: West Bank geographical map including Sourif region.
(http://www.arij.org/paleye/hebron/hebronh.gif.html,(23-3-2010))

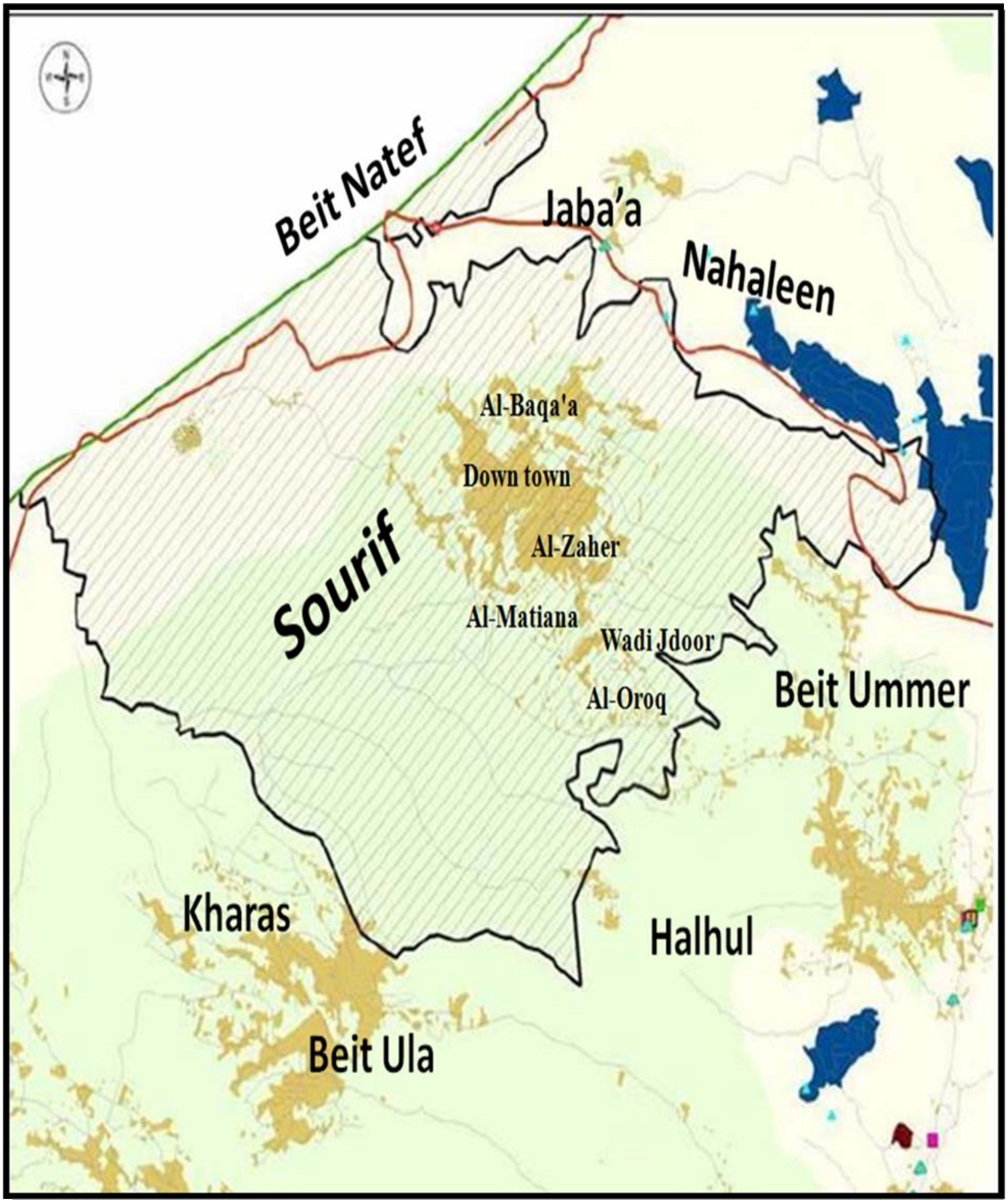

Figure 1.6b: Geographical map of Sourif city, showing the six investigated regions in the city. (http://www.arij.org/paleye/hebron/hebronh.gif.html,(23-3-2010))

Chapter Two

Methodology and Statistical Analysis

Chapter Two

Methodology and Statistical Analysis

2.1 Introduction

The fact that radon can not be detected with the human senses is resulted in developing so many measurements techniques and procedures to collect radon concentration levels data.

Radon measurement is concerned mainly in radon activity measurements, which is the rate at which radon atoms decays. As activity is proportional to the number of radon atoms present, it is required for the calculations of radon concentration levels. The radon concentrations are measured using radon detectors that have been developed several decades ago. A radon detector is a device used to detect the presence of radon gas as well as its amount. Furthermore, detectors were designed to test the presence of radon gas inside dwellings and provide us with the data necessary for calculating the radon concentration levels (Hotzl, and Winkler, 1994).

Radon concentration levels are generally measured either by using passive measurements techniques or using active techniques (Frank, and Benton, 1979; Al-Kofahi, *et al.,* 1992; Awawdeh, 2001). In the next section, we shall discuss briefly these techniques separately.

2.2 Radon Measurements Techniques:

There are several types of measurement systems for measuring radon levels and its progeny. It might be difficult to classify them, but the major concern is distinguishing between the measurements techniques by examining the time resolution of the considered technique (Durrani, and Bull, 1987). Generally speaking, there are two basic techniques used in monitoring the radon concentration levels. These first one is the so called the passive (a long-term test) and second is the active (a short-term test) depending on the definition applied term.

The most common passive technique is the so called Solid State Nuclear Track Detectors (SSNTD's) or the CR-39 detectors; while the most common active technique is the so called working-level meter (WLM). It has been shown experimentally that the SSNTD's technique is more reliable for the integrated and long-term measurement of indoor radon concentration levels (Al-Kofahi, *et al.,* 1992). We shall discuss these techniques briefly in the following subsections.

2.2.1 The Active Technique (short-term test detectors):

The active technique uses a number of different radon detectors and requires a power supply for operation. The most common detectors used are: charcoal canisters, continuous monitor*s*, charcoal liquid scintillation and the working-level (WL) meters (EPA, 2003). Accordingly, scientists have developed several active techniques for monitoring radon in the environment and the most well known ones are:

2.2.1.1 Continuous Monitors' Technique: This technique is usually used for research studies, and is useful to obtain an indication of radon local concentration. This technique gives the time evolution of radon concentration. Hence, the results of counting are reported continuously prior to long term evaluation as required. Then, the obtained results may be downloaded into a computer and analyze (Durrani, and Bull, 1987).

2.2.1.2 Grab-Sampling Technique: This technique is useful for quick estimation of radon concentration levels, depending on the collected air sample at a single point over a short period of time, then analyzing it (Durrani, and Bull, 1987).

2.2.1.3 Time-Integrated Technique: This technique provides a single concentration measurement averaged over the exposure period. It is used to estimate the annual average of radon concentration levels over a given area (Durrani, and Bull, 1987).

2.2.1.4 Working-Level (WL) Technique: This technique is one of the mostly used active techniques. It represents any group of ^{222}Rn short half-life daughters that present in one liter of air and with a total capacity emission of $1.3x10^5$ MeV of alpha energy (EPA, 2003). If a closed volume is constantly supplied with radon, the concentration of short-lived daughters will increase until an equilibrium is reached where the rate of decay of each daughter will equal that of the radon itself (EPA, 2003).

Atypical example is the WL meter model TN-WL-02 was manufactured by Thomas and Neilsen Electronics was also used to measure the indoor radon-daughter concentration. Such kind of detectors can be used to provide a direct method for recording the alpha counts as a function of time (Awawdeh, 2001; Leghrouz, *et. al.,* 2008).

The value of the WL of alpha particles energy resulting from the disintegration of radon daughters of ^{214}Po, ^{214}Pb and ^{214}Bi when they are in equilibrium has a total value of 3.7 kBq/m^3 (100 pCi/litre) (Grasty, and LaMarre, 2004).

The working-level meter has a recorder and a thermal printer to provide readings every hour. The WL meter unit can be used to convert alpha counts to the equilibrium equivalent concentration of radon unit (EER) according to the following conversion formula:

$$1\frac{\mathbf{Bq}}{\mathbf{m^3}}\ (\mathbf{EER}) = \mathbf{2.7 \times 10^{-4}}\ WL \qquad (2.1)$$

With

$$\mathbf{WL} = \frac{\mathbf{alpha\ counts}}{\mathbf{T_s - 0.5}}\mathbf{CF} \qquad (2.2)$$

Where WL: is the abbreviations of working-level.

CF: is the calibration factor which is equal to 5 alpha counts per hour per milli working-level (mWL).

T_s: is the sampling time in hours (Thomson, and Nilsson, 1990).

A short term detector is generally placed on a low level of a building for a few hours, after the specified time period, the detector is then taken and sent to a lab for analysis the radon concentration levels (Gerorge, 1999).

2.2.2 The Passive Technique (long-term technique):

The passive radon detectors include the alpha track detectors and electrets ion chambers (EPA,2003) . In this technique, detectors are left in dwellings for a long period of time that varies from a few days to several months. Since radon levels change with seasons, this course of action is the best way to test radon levels throughout the year. Furthermore, they are more suitable for the assessment of radon exposure over long time scales at moderate cost (Gerorge, 1999). Typical examples on such devices are the diffusion sampler and SSNTDs.

2.2.2.1 The Diffusion Sampler:

A diffusion sampler consists of a tube with a detector located at one end of the diffusion zone formed by the tube, while the other end is open to the atmosphere to be monitored. If the tube put in length more than 30 cm on the ground, only ^{222}Rn concentration is being measured. This is because thoron (^{220}Rn) decays before it reaches the sensitive volume of the detector. In other words, a permeation sampler assures a more efficient way to eliminate the ^{220}Rn, by using a polymeric membrane (namely a polyethylene film a few tens of a μm thick) in which radon might be dissolved and then diffused. In particular, a permeation sampler can be simply formed by a heat-sealed plastic bag made of polyethylene containing the detectors (Battista, and Gray, 1988).

2.2.2.2 The Solid State Nuclear Track Detectors (SSNTDs):

The Solid State Nuclear Track Detectors (SSNTDs) are the most common examples on passive technique that had been developed 50 years ago (Darby,*et al.,* 2001; Cecchini, *et al.,* 2003). The SSNTDs are increasingly being used to obtain the time integrated concentration levels of indoor ^{222}Rn (Abu-Jarad, and Fermlin, 1981; Subba Ramu, *et al.,* 1992). This is because they sensitive to alpha-particles and stability against various environmental conditions and high degree of optical clarity (Danis,*et al.,* 2001).

There are several kinds and shapes of radon SSNTDs dosimeters used in the field of radon dosimetry and the most popular used ones are the LR-115 and the CR-39 (Darby, *et al.,* 2001). The principle of radon concentrations measurements in this technique is based on the production of track in the detector due to alpha particles emitted from radon and its progeny. After the exposure period detectors are chemically etched in NaOH and they counted under the optical microscope (ICRP, 1993), with a 160 times magnified. The number of etches are then used to calculate the radon track density. The measurement track density is then converted into radon concentrations according to a certain cerebration equation (ICRP, 1993).

2.2.2.2.1 The LR-115 Dosimeter:

The LR-115 detector type is used for measuring the indoor radon concentration levels since 1978 in various areas in United Kingdom. The LR-115 alpha track detector type is a plastic manufactured by Kodak Pathé in France (Garakani, 1993). A typical LR-115 dosimeter consists of a cylindrical can and LR-115 a detector size (1.5 cm × 2 cm) fixed at the top inside surface the cylinder. The sensitive lower surface of the detector is freely exposed to the emergent radon so that it is capable of recording the alpha particles resulting from the decay of radon in the can (El-Zaher, and Fahmib, 2008). Atypical LR-115 dosimeter is shown in Fig. (2.1).

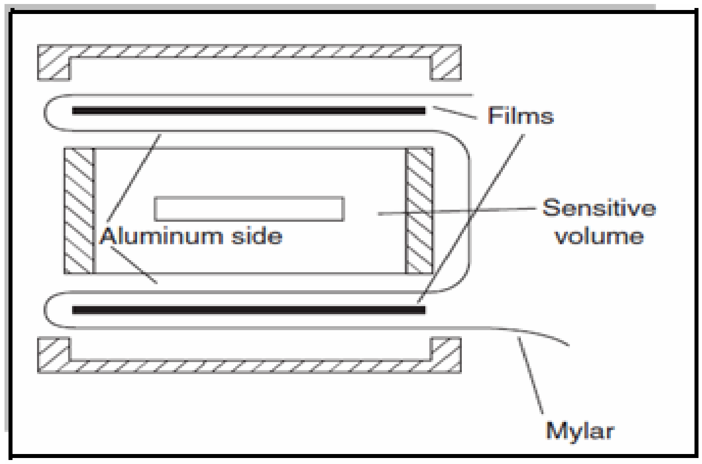

Figure 2.1: Atypical LR-115 dosimeter cross section (Campi, *et al,* 2004).

2.2.2.2.2 The CR-39 Detectors:

The CR-39 detector is one of the most popular SSNTDs used in estimating the radon concentration levels on the long term basis. The detector was first discovered and developed in Berkeley in 1933 (Cartwright, *et al.,* 1990). It is manufactured commercially by Pershore Mouldings Ltd.,U.K, using polyallyl diglycol carbonate (PADC) material to produce a TASTRAK' Plastic (TASTRAK is a polymer that was developed at Bristol University). The chemical structure of CR-39 is $C_{12}H_{18}O_7$ and the monomer structure is (Track Analysis Systems Ltd, 2005).

$$CH_2{=}CH{-}CH_2{-}O{-}CO{-}O{-}CH_2CH_2{-}O{-}CH_2CH_2{-}O{-}CO{-}O{-}CH_2{-}CH{=}CH_2$$

The CR-39 material is transparent to visible spectrum and is almost completely opaque to ultraviolet spectrum with an index of refraction smaller than that of crown glass. These detectors are used in radioactivity measurements for radon detection, neutron dosimetry, and fusion studies for temperatures up to 100^{o}C (Track Analysis Systems Ltd, 2005).

The CR-39 detectors are sensitive for alpha particles having energies up to 4 MeV (Khan, *et al.,* 1990). The general method of using CR-39 detectors is based on placing the detectors in buildings near the ground so as to be exposed directly to the air and radon for a specific period of time. After the radon gas decays and alpha particle is released, alpha particle hit the detectors and breaks the polymers chemical bonds, leaving points on the detector surface as points (open circles) that can not be seen with the naked eye. Therefore, chemical treatment (etching) is required to explore these points (tracks). This can be accomplished by using sodium hydroxide (NaOH) which resulted in hulk etching of the surface of the polymer. Heating the detector for a period of time (~ 7 hours) at 72 ^{o}C will exhibit the effects of the alpha particles, and make it possible to count the alpha particle tracks by means of a magnified microscope. The points of alpha particle track density are proportional directly to the concentration of radon in the air (Camplin, *et a1.,* 1988).

The SSNTDs are the most used techniques in measuring radon concentration levels in dwellings and we recommend it strongly to be used in this study.

2.3 Comparison Between Detectors

There are different methods of measurements used to determine the radon concentrations in the environment. Each method has its own advantages and disadvantages and users must decide which method is best to be used. But the Public Health Division (PHD) recommends a method which will provide an annual average radon concentration in the investigated living area (Cohen, *et al.,* 1994). In the following, we shall discuss some of the advantages and disadvantages of methods introduced in section (2.2).

The working level technique is expensive, large sized, short term and can be handled by technical staff.

The LR-115 detector is characterized by its simplicity, long-term integrated read out, and high sensitivity to alpha-particle radiation. It detects alpha particle with energy below 4.0 MeV. A residual energy between 1.6 and 4.7 MeV are registered as bright track-holes (Misdaq, *et al.,* 1998). These detectors are available, ease of handling and low cost but does not give a guideline for uncertainty evaluation of alpha particle (ICRP, 1993).

The CR-39 detector is very sensitive to alpha-particles and insensitive to electromagnetic radiation and electrons (for example Beta and Gamma particles, X-rays). It has a very low background, high reproducibility and a detectable energy range of 6.00-7.69 MeV for alpha particles emitted from radon daughter ^{218}Po and ^{214}Po (Tokonami, *et al.,* 1996). This technique is easy to use, practical and cheap, and unaffected by the climate change parameters that would normally affect the level of radon (Wilkening, *et al.,* 1972). The overall uncertainty in the counting system has been estimated to be between 10–20 % (Jackson, and French, 1997). It is for these properties and advantages, CR-39 detectors are chosen to be as reliable detectors in this study. Therefore, it is of great importance to introduce the device used in measuring the alpha particle track densities. This device is called the dosimeter and it will be discussed in the following section.

2.4 The Dosimeter Structure

The well known SSNTDs technique is usually used for long-term measurements inside houses and public dwellings (Garakani, 1993) require a calibrated dosimeter for monitoring the alpha particle tracks. In this study, we shall adopt the dosimeter prepaid by Yarmouk group in order to make use of the derived calibration equation to convert the number of tracks to radon concentration levels. The structure of the calibrated CR-39 dosimeter used by Yarmouk group consists of CR-39 (polyallyl diglycol carbonate (PADC)) detectors having dimensions of 10.0 mm×10.0 mm×0.5 mm. All detectors were engraved by the serial number on each detector for ease of identification. The detector was inserted in a flat position at the bottom of a plastic cup and was held in place by a small piece of blue-tack, as shown in Fig. (2.2).

The plastic cup has dimensions of 70.0 mm diameter orifice, 50.0 mm diameter base and 65.0 mm depth. The top of the cup was completely covered with permeable cling film (polyethylene foil) to allow only ^{222}Rn gas to pass through the film and to exclude the nongaseous radon daughters from entering the dosimeter. Thus, the entry of radon progeny and dust are prevented from being present in the ambient air (Hassan, 1996). A complete typical calibrated dosimeter is exhibited in Fig. (2.2)

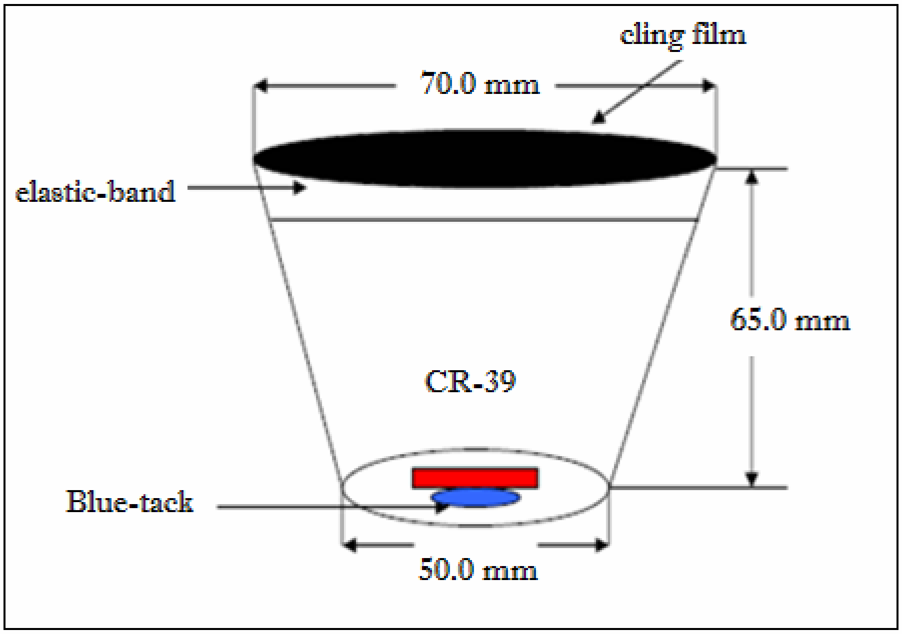

Figure 2.2: Typical CR-39 dosimeter (Abu-smreh, 2005).

2.5 The Dwellings and Exposure

Radon concentrations in Sourif dwellings are measured using CR-39 detectors. A total number of 35 houses (single and two level houses) are selected randomly from six different locations in Sourif city (AL-Oroq, Down town, Wadi Jdoor, AL-Matiana, AL-Baqa'a and AL-Zaher). More details about the dwellings characteristics are discussed in Appendix A.

195 dosimeters were prepared and distributed inside and outside each dwelling. Indoors, the dosimeters were usually distributed in bedrooms, kitchens, bathrooms, living room and storage rooms. Dosimeters are placed at a high of 0.5 m and left in place for almost (160-180) day. The period started from August 1, 2009 to January 31, 2010. By the end of this period, only 138 dosimeters were collected. The remaining 57 dosimeters were lost or mistreated. A summary of the distributed dosimeters is shown Table (2.1).

Table 2.1: The number of detectors distributed in Sourif city.

Number of missed detectors	Number of collected detectors	Number of distributed detectors	Location
12	15	27	**Al-Oroq**
11	42	53	**Al-Matiana**
6	24	30	**Down town**
2	23	25	**Wadi Jdoor**
14	19	33	**Al-Baqa'a**
12	15	27	**Al-Zaher**
57	**138**	**195**	**Total**

2.6 Etching Processes

By the end of this period, the dosimeters were collected and the detectors were taken out of the dosimeters and prepared for etching processes.

The collected detectors were chemically etched using a 6.25 N-solution of NaOH, at a temperature of 72^{o}C, for almost 7 hours. At the end of the etching process, the detectors were washed thoroughly with distilled water and then left to dry, after that the number of etching points (track points) on each detector was counted visually using an optical microscope (Al-Sharif *et al.,* 2001).

2.7 Counting the Number of Tracks and Data Collections

The drained detectors (see section 2.6) after etching processes are divide the detector surface into 10 parts of which has an area equal to 0.1cm^2 (see Fig. (2.3a)). Then, each of these parts(0.1cm^2) is divided into 7.5 portions for track density inspection using a 160 times magnified optical microscope where the microscope maximum view area is about 0.0133cm^2. A typical slide show of tracks on one of the detectors is exhibited in Fig. (2.3b).

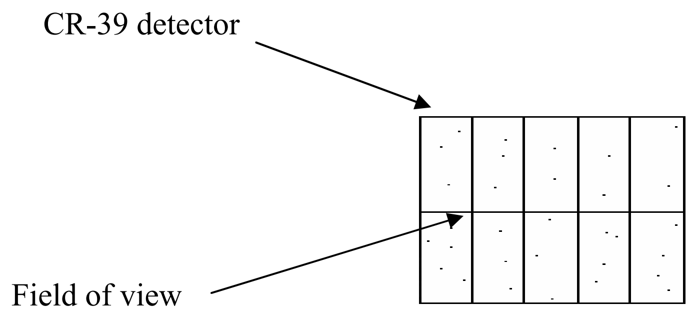

Figure 2.3a: Schematic representations of the field views on each detector.

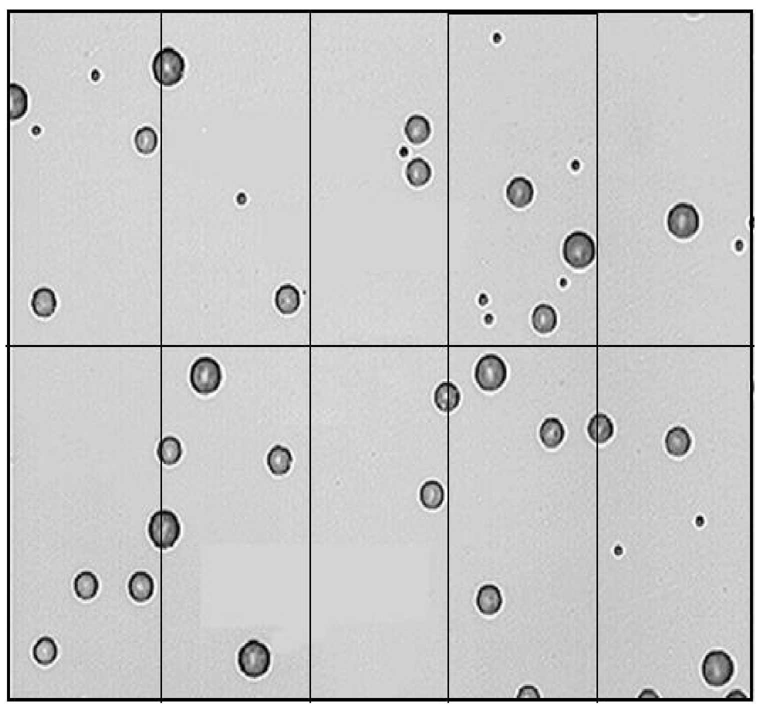

Figure 2.3b: A typical detector showing the field views magnified 160 times.

The number of tracks in each field view was counted for all portions in the field view and the obtained data were averaged and tabulated in Table (2.2). These data will be used to calculate the radon concentration levels. The general method of approach will be discussed in Chapter 3.

Table 2.2a: The average number of tracks in each field view of area $0.0133cm^2$.

$\rho=\frac{\#tracks}{cm^2}$	The average number of tracks in each field view											Room	Floor	House	Main Zone
	f(AM)	f10	f9	f8	f7	f6	f5	f4	f3	f2	f1				
842.12	11.2	8	9	21	14	15	10	8	8	9	10	Bedroom	2	1	Al-Oroq
1007.5	13.4	4	10	4	8	4	18	26	22	16	22	Bedroom	1	1	Al-Oroq
1323.3	17.6	8	16	18	11	15	20	25	22	23	18	Kitchen	1	1	Al-Oroq
518.8	6.9	3	8	8	3	4	13	10	5	10	5	Bathroom	1	1	Al-Oroq
466.17	6.2	4	10	9	8	7	4	4	7	5	4	Livingroom	1	1	Al-Oroq
751.88	10.0	18	4	3	6	8	14	13	11	12	11	Bedroom	1	4	Al-Oroq
1097.7	14.6	16	23	25	20	11	8	14	9	10	12	Kitchen	1	4	Al-Oroq
473.68	6.3	6	5	8	10	11	5	7	4	2	5	Livingroom	1	4	Al-Oroq
345.86	4.6	7	5	4	1	3	2	6	6	6	6	Bedroom	1	5	Al-Oroq
526.3	7.0	13	8	3	4	6	8	9	2	10	7	Kitchen	1	5	Al-Oroq
315.79	4.2	10	4	2	2	4	1	4	5	5	7	Outdoor	1	5	Al-Oroq
1939.8	25.8	21	20	42	24	21	32	30	23	23	22	Llivingroom	1	3	Al-Oroq
375.9	5.0	4	3	2	11	4	9	4	3	5	5	Kitchen	1	2	Al-Oroq
518.8	6.9	7	13	4	6	12	7	3	5	5	7	Livingroom	2	2	Al-Oroq
4150.4	55.2	64	55	48	62	66	70	55	47	40	45	Bathroom	1	4	Al-Oroq
1127.8	15.0	21	20	8	9	15	8	10	12	25	22	Bedroom	2	6	Down town
1067.67	14.2	15	7	4	10	22	33	8	5	16	22	Kitchen	2	6	Down town
691.7	9.2	7	10	7	9	13	10	7	6	12	11	Outdoor	2	6	Down town
503.76	6.7	6	5	7	6	6	9	6	8	6	8	Bathroom	2	6	Down town
616.5	8.2	9	13	3	6	7	7	7	5	15	10	Livingroom	2	6	Down town
624.1	8.3	8	10	12	6	7	8	7	12	8	5	Bedroom	2	7	Down town
947.4	12.6	23	11	8	9	10	10	6	13	22	14	Kitchen	2	7	Down town
804.5	10.7	6	10	11	6	10	9	12	8	10	9	Outdoor	2	7	Down town
1067.67	14.2	16	10	18	14	13	18	12	15	12	14	Bathroom	2	7	Down town
819.55	10.9	9	20	12	14	14	13	13	4	4	6	Livingroom	2	7	Down town
1751.88	23.3	26	28	15	28	17	17	18	32	25	27	Storage	1	7	Down town
496.24	6.6	12	5	2	5	8	3	4	4	15	8	Bedroom	2	8	Down town
1097.7	14.6	17	8	10	23	10	23	17	16	14	8	Kitchen	2	8	Down town
466.17	6.2	3	5	4	9	3	8	10	4	7	9	Outdoor	2	8	Down town
819.55	10.9	6	13	10	8	9	10	13	10	12	18	Bathroom	2	8	Down town
744.36	9.9	8	9	8	11	13	17	10	10	7	6	Livingroom	2	8	Down town
458.6	6.1	4	5	5	4	7	7	7	8	2	12	Storage	2	8	Down town
1203.1	16.0	18	43	3	4	22	20	11	20	9	10	Storage	1	8	Down town
834.59	11.1	9	10	13	18	8	12	8	8	12	13	Bedroom	2	9	Down town
669.17	8.9	4	8	6	17	12	9	14	8	7	4	Kitchen	2	9	Down town
428.57	5.7	12	3	4	4	8	6	4	4	5	7	Outdoor	2	9	Down town
1593.98	21.2	20	24	23	23	24	22	25	23	14	14	Bathroom	2	9	Down town
759.39	10.1	8	12	8	14	12	11	10	9	9	8	Livingroom	2	9	Down town
721.8	9.6	5	8	8	15	7	10	12	11	7	13	Storage	1	9	Down town
804.5	10.7	11	12	10	10	7	4	8	9	12	24	Bedroom	2	10	Wadi Jdoor
2308.27	30.7	35	36	24	35	30	30	23	48	33	13	Bedroom	1	10	Wadi Jdoor

Table 2.2b: The average number of tracks in each field view of area $0.0133cm^2$.

$\rho = \frac{\#tracks}{cm^2}$	The average number of tracks in each field view											Room	Floor	House	Main Zone
	f(AM)	f10	f9	f8	f7	f6	f5	f4	f3	f2	f1				
1195.489	15.9	19	20	10	20	21	16	12	16	17	8	Kitchen	2	10	Wadi Jdoor
571.4286	7.6	12	12	6	6	8	8	10	5	4	5	Outdoor	2	10	Wadi Jdoor
571.4286	7.6	6	7	4	8	10	7	5	13	8	8	Bathroom	2	10	Wadi Jdoor
766.9173	10.2	8	15	8	12	7	10	7	10	14	11	Bathroom	1	10	Wadi Jdoor
571.4286	7.6	7	13	9	4	7	9	8	10	5	4	Livingroom	2	10	Wadi Jdoor
751.8797	10.0	8	5	7	6	13	10	14	12	10	15	Livingroom	1	10	Wadi Jdoor
909.7744	12.1	22	16	14	8	9	12	7	8	8	17	Storage	1	10	Wadi Jdoor
1624.06	21.6	24	18	12	18	35	24	38	15	18	14	Bedroom	1	11	Wadi Jdoor
736.8321	9.8	13	6	7	9	13	11	11	8	8	12	Kitchen	1	11	Wadi Jdoor
578.9474	7.7	8	9	5	2	6	10	12	5	10	10	Outdoor	1	11	Wadi Jdoor
669.1729	8.9	12	10	14	3	4	10	9	12	9	6	Bathroom	1	11	Wadi Jdoor
684.2105	9.1	12	13	10	9	10	4	10	8	9	6	Livingroom	1	11	Wadi Jdoor
1045.113	13.9	33	27	8	17	14	10	10	7	8	5	Kitchen	2	12	Wadi Jdoor
676.6917	9.0	11	9	15	8	11	8	11	9	8	6	Outdoor	2	12	Wadi Jdoor
383.4587	5.1	7	7	6	8	4	6	7	3	1	2	Bathroom	2	12	Wadi Jdoor
1406.015	10.8	16	10	10	12	7	5	15	13	12	8	Outdoor	1	13	Wadi Jdoor
1406.015	18.7	18	26	26	19	38	9	7	4	16	24	Livingroom	1	13	Wadi Jdoor
751.8797	10.0	7	15	13	11	17	9	5	12	4	7	Bedroom	1	14	Wadi Jdoor
601.5038	8.0	8	11	7	7	8	8	4	6	11	10	Bedroom	1	15	Wadi Jdoor
293.2331	3.9	3	7	1	5	6	5	5	3	2	2	Kitchen	1	15	Wadi Jdoor
684.2105	9.1	8	8	9	12	13	8	13	9	6	5	Bathroom	1	15	Wadijdoor
729.3233	9.7	20	15	15	4	5	10	11	6	6	5	Bedroom	1	16	Al-Matiana
699.2481	9.3	6	10	14	7	10	7	8	14	8	9	Outdoor	1	16	Al-Matiana
639.0977	8.5	11	13	7	5	2	7	7	10	12	11	Bathroom	1	16	Al-Matiana
109.0226	14.5	12	15	15	8	15	30	14	13	10	13	Livingroom	1	16	Al-Matiana
1601.504	21.3	17	23	18	27	22	38	20	26	14	8	Bedroom	2	17	Al-Matiana
511.2782	6.8	4	4	13	8	8	2	6	8	9	6	Kitchen	2	17	Al-Matiana
375.9399	5.0	7	6	3	6	10	4	2	5	3	4	Outdoor	2	17	Al-Matiana
616.5414	8.2	16	12	10	7	5	6	8	4	8	6	Bathroom	2	17	Al-Matiana
842.1053	11.2	8	11	10	7	9	11	16	15	14	11	Livingroom	2	17	Al-Matiana
451.1278	6.0	3	8	5	4	4	4	4	5	10	13	Bedroom	1	18	Al-Matiana
781.9549	10.4	6	6	15	14	13	6	12	11	13	8	Kitchen	1	18	Al-Matiana
684.2105	9.1	9	11	17	7	6	6	6	10	13	6	Bathroom	1	18	Al-Matiana
1142.857	15.2	27	23	12	10	23	21	16	8	6	6	Livingroom	1	18	Al-Matiana
616.5414	8.2	7	4	3	9	10	9	6	9	11	14	Bedroom	2	19	Al-Matiana
1315.79	17.5	16	10	17	17	11	16	22	15	19	32	Kitchen	2	19	Al-Matiana
556.391	7.4	7	10	6	7	6	18	7	5	3	5	Outdoor	2	19	Al-Matiana
609.0226	8.1	16	4	5	3	10	4	7	12	4	16	Bathroom	2	19	Al-Matiana
1037.594	13.8	14	12	24	18	20	13	11	10	10	6	Livingroom	2	19	Al-Matiana
932.3308	12.4	17	16	11	11	9	15	8	12	13	12	Storage	1	19	Al-Matiana
406.015	5.4	8	5	5	3	3	3	4	3	9	11	Kitchen	2	20	Al-Matiana
518.797	6.9	8	4	10	11	3	4	6	8	8	7	Outdoor	2	20	Al-Matiana

2330.827	31.0	21	20	32	55	38	46	40	22	20	16	Bedroom	1	21	Al-Matiana

Table 2.2c: The average number of tracks in each field view of area $0.0133 cm^2$.

$\rho = \frac{\#tracks}{cm^2}$	The average number of tracks in each field view											Room	Floor	House	Main Zone
	f(AM)	f10	f9	f8	f7	f6	f5	f4	f3	f2	f1				
1218.045	16.2	22	10	13	20	15	16	18	18	17	13	Bedroom	2	21	Al-Matiana
413.5338	5.5	8	13	7	3	5	1	5	5	2	6	Outdoor	2	21	Al-Matiana
992.4812	13.2	12	9	16	13	15	20	18	12	10	7	Livingroom	1	21	Al-Matiana
413.5338	5.5	4	5	2	3	8	4	8	10	6	5	Livingroom	2	21	Al-Matiana
1022.556	13.6	12	13	9	17	16	13	11	19	11	15	Livingroom	2	22	Al-Matiana
691.7293	9.2	13	12	6	11	12	9	7	7	7	8	Bedroom	2	23	Al-Matiana
661.6541	8.8	9	9	11	3	6	4	8	9	17	12	Kitchen	2	23	Al-Matiana
270.6767	3.6	4	2	5	3	5	4	2	3	3	5	Outdoor	2	23	Al-Matiana
827.0677	11.0	10	8	7	12	14	16	23	10	4	6	Bathroom	2	23	Al-Matiana
1270.677	16.9	16	18	17	16	19	24	18	16	10	15	Storage	1	23	Al-Matiana
721.8045	9.6	8	8	5	13	13	15	5	8	10	11	Bedroom	1	24	Al-Matiana
969.9248	12.9	7	14	11	16	15	10	13	11	10	22	Bathroom	1	24	Al-Matiana
593.985	7.9	7	10	7	9	4	4	7	8	14	9	Livingroom	1	24	Al-Matiana
1120.301	14.9	15	26	18	12	14	13	14	16	14	7	Bedroom	1	25	Al-Matiana
1022.556	13.6	17	11	8	12	5	14	15	12	24	18	Kitchen	1	25	Al-Matiana
1947.368	25.9	39	34	24	30	36	22	10	21	26	17	Bathroom	1	25	Al-Matiana
436.0902	5.8	6	4	8	8	10	5	4	2	6	5	Livingroom	1	25	Al-Matiana
864.6617	11.5	10	12	17	12	15	10	6	12	9	12	Bedroom	1	26	Al-Matiana
857.1429	11.4	11	6	10	9	14	14	19	11	11	9	Kitchen	1	26	Al-Matiana
676.6917	9.0	17	13	4	12	10	6	5	12	5	6	Livingroom	1	26	Al-Matiana
887.2181	11.8	8	10	12	5	6	13	21	16	14	13	Bedroom	2	27	Al-Baqa'a
676..69173	19.8	17	11	43	32	24	15	13	20	12	11	Kitchen	2	27	Al-Baqa'a
601.5038	8.0	5	9	6	7	6	15	8	11	8	5	Outdoor	1	27	Al-Baqa'a
6127.82	81.5	73	80	87	69	77	83	97	78	91	80	Bathroom	2	27	Al-Baqa'a
684.2105	9.1	11	4	8	9	12	6	12	11	6	12	Livingroom	2	27	Al-Baqa'a
661.6541	8.8	6	5	8	17	14	11	5	8	6	8	Storage	2	27	Al-Baqa'a
2037.594	27.1	10	23	42	27	28	32	33	18	27	31	Bedroom	2	28	Al-Baqa'a
1285.714	17.1	13	12	19	18	25	23	19	15	18	9	Kitchen	2	28	Al-Baqa'a
2112.782	28.1	41	45	37	28	40	25	17	16	17	15	Outdoor	2	28	Al-Baqa'a
849.6241	11.3	16	12	16	13	8	14	11	9	8	6	Bathroom	2	28	Al-Baqa'a
706.7669	9.4	6	8	5	11	13	11	11	13	7	9	Livingroom	2	28	Al-Baqa'a
684.2105	9.1	13	12	7	8	12	12	4	11	5	7	Bedroom	2	29	Al-Baqa'a
390.9774	5.2	6	7	4	5	5	4	3	6	6	6	Outdoor	2	29	Al-Baqa'a
375.9399	5.0	3	7	4	5	5	4	3	10	5	4	Bathroom	2	29	Al-Baqa'a
714.2857	9.5	12	6	8	7	12	8	6	8	16	12	Livingroom	2	29	Al-Baqa'a
6842.105	9.1	11	21	12	15	15	1	2	5	7	2	Kitchen	1	30	Al-Baqa'a
571.4286	7.6	10	9	8	7	9	4	8	6	8	7	Livingroom	1	30	Al-Baqa'a
428.5714	5.7	3	6	4	5	4	7	7	5	9	7	Outdoor	2	31	Al-Baqa'a
609.0226	8.1	12	10	8	10	7	9	9	2	8	6	Livingroom	2	31	Al-Baqa'a
1263.158	16.8	13	17	11	20	28	16	17	11	13	22	Bedroom	1	32	Al-Zaher

669.1729	8.9	8	7	6	11	15	10	7	12	7	6	Kitchen	1	32	Al-Zaher
285.7143	3.8	3	3	5	2	2	4	3	4	7	5	Outdoor	1	32	Al-Zaher
383.4587	5.1	5	7	4	6	3	8	5	2	6	5	Bathroom	1	32	Al-Zaher

Table 2.2d: The average number of tracks in each field view of area $0.0133cm^2$.

ρ $\frac{\#tracks}{cm^2}$ =	The average number of tracks in each field view											Room	Floor	House	Main Zone
	f(AM)	f10	f9	f8	f7	f6	f5	f4	f3	f2	f1				
646.6165	8.6	11	7	17	10	7	6	6	8	6	8	Livingroom	1	32	Al-Zaher
436.0902	5.8	7	7	6	3	7	8	10	4	2	4	Kitchen	1	33	Al-Zaher
413.5338	5.5	6	8	5	4	6	5	8	7	5	3	Outdoor	1	33	Al-Zaher
894.7368	11.9	6	9	17	23	14	9	10	12	10	9	Livingroom	1	33	Al-Zaher
766.9173	10.2	13	4	6	12	5	11	17	15	11	8	Bedroom	1	34	Al-Zaher
428.5714	5.7	5	2	7	9	7	6	4	7	2	8	Kitchen	1	34	Al-Zaher
187.9699	2.5	3	2	2	3	3	2	2	2	2	4	Kitchen	2	34	Al-Zaher
1000	13.3	20	12	15	15	14	10	17	12	9	9	Outdoor	2	34	Al-Zaher
751.8797	10.0	9	11	18	14	12	7	6	6	10	7	Livingroom	1	34	Al-Zaher
1195.489	15.9	17	19	26	11	17	19	15	13	10	12	Bedroom	2	35	Al-Zaher
1338.346	17.8	20	13	16	17	5	12	18	22	25	30	Livingroom	2	35	Al-Zaher

Chapter Three

Calculations and Results

3.1 Introduction

3.2 Statistical Analysis of the Basic Radiation Quantities

3.2.1 The Arithmetic Mean (AM)

3.2.2 The Geometric Mean (GM)

3.3 Radon Concentration Levels (C_{Rn})

3.4 Annual Radon Effective Dose Equivalent

3.5 Results

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3.5.2 Down Town Region

3.5.3 Wadi Jdoor Region

3.5.4 AL-Matiana Region

3.5.5 Al- Baqa’a Region

3.5.6 Al-Zaher Region

Chapter Three

Calculations and Results

3.1 Introduction

In this chapter, the data representing the number of tracks obtained for each detector collected from the investigated dwellings in Sourif city (See Table (2.2)) will be analyzed on statistical basis to estimate the arithmetic means, the geometric means, and the concentration levels. The obtained results for the radon concentration levels will be used to estimate the annual effective doses. The results will be discussed and compared to the international assigned standard of radon.

3.2 Statistical Analysis of the Basic Radiation Quantities

Statistical methods and concepts are used in this study to analyze the obtained data to get the required results of radon concentration levels and the annual effective dose. The arithmetic, the geometric means and standard deviation are introduced and discussed.

3.2.1 The Arithmetic Mean (AM):

For the list of data in Table (2.2), which represents the track's density in each field view, the arithmetic mean (AM) is defined as the sum of all the track densities in all field views obtained for each detector divided by the number of field views. Thus,

$$\mathbf{AM} = \bar{\mathbf{X}} = \frac{1}{n}\sum_{i=1}^{n} \mathbf{X}_i = \frac{1}{n}(\mathbf{X}_1 + \cdots + \mathbf{X}_n) \qquad (3.1)$$

Where **n** is the number of field views (10 field views), $\mathbf{X_i}$ the number of tracks in the ith field view.

3.2.2 The Geometric Mean (GM):

The geometric mean (GM) for n different number of data (For example a number of track densities for n field views) is defined as the nth root of the product obtained by multiplying each single measurement by the following it measurement until a total number of n data are multiplied. Mathematically,

The obtained arithmetic mean and the geometric mean are both listed in Table (2.2).

3.3 Radon Concentration Levels ($\mathbf{C_{Rn}}$)

The results of the average track density of ^{222}Rn presented in Table (2.2) for each detector was employed to calculate the radon average concentration levels **($\mathbf{C_{Rn}}$)** in Bq/m^3 using the calibration factor obtained at Bristol University and adopted by Yarmouk research group (Swedjemark, and Makitalo, 1990; AL-Kofahi, *et al.,* 1992; Kullab*, et al.,* 1997; Dabayneh and Awawdeh, 2007). According to the Yarmouk group, the radon concentration levels can be expressed in terms of track density as:

$$\mathbf{C_{Rn}} = \frac{\mathbf{C_o t_o \rho}}{\mathbf{\rho_o t}} \qquad \mathbf{(3.3a)}$$

Where;

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

t_o : is the exposure time of detector in radon chamber is equal 2 days (= 48 hours).

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

The total area scanned in the detector (A) = 0.0133 cm^2

So

$$\rho = \frac{(Number\ of\ protions) \times (Total\ number\ of\ tracks\ in\ each\ protions)}{(Number\ of\ protions) \times (Area\ of\ each\ protions\ )}$$

$$\rho = 75.188 \times (average\ \#of\ tracks\ in\ each\ view)$$

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.

$$C_{Rn} = \frac{90 \times 10^3 \times 2}{3.3 \times 10^4} \times 75.\frac{188}{t} \times \bar{F}$$

$$C_{Rn} = 410 \times \frac{\overline{F}}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots Bq/m^3 \qquad \textbf{(3.3b)}$$

Where;

$\bar{F}$ = the average number of tracks in each field view.

3.4 Annual Radon Effective Dose Equivalent (E_{AEDE})

The annual effective dose equivalent (E_{AEDE}) in (mSv/y) attributed to the inhalation of ^{222}Rn in dwelling, can be calculated according to the following equation (ICRP, 1993):

$$E_{AEDE} = \frac{C_{Rn} \times F \times DCF \times t}{\left(\frac{3700Bq}{m^3}\right) \times (170h)} \qquad (3.4)$$

Where;

C_{Rn}: is the concentration of radon in (Bq/m^3).

F: is the equilibrium factor which is taken as 0.4 according to International Commission on Radiological Protection (ICRP) agency (ICRP, 1994a).

DCF: is the dose conversion factor = 3.88 mSv/WLM (ICRP, 1994b) .

WLM: is the working level-month for exposure attained by 170 h breathing in air in which radon concentration level is 3700 Bq/m^3.

t: is the mean time per year when the occupancy factor = 0.8 (~19hr per day) at homes for populations ($t=365\times24\times0.8=7000$ hr).

3.5 Results:

In this section we shall present our results that are obtained from the collected data (see Tables (2.2)), obtained from the six major sectors (AL-Oroq, Down town, Wadi Jdoor, AL-Matiana, AL-Baqa'a and AL-Zaher) investigated in Sourif city. The results are obtained using statistical equations (3.1-3.4). A summary of the results for the indoor radon concentration levels measured in the air of 35 dwellings selected randomly from the monitored zones in Sourif city during time period of August 1, 2009 to January 31, 2010 are summarized in Table (3.1). The table summary includes the number of collected detectors (N), the concentration of radon (C_{Rn}) in (Bq/ m^3), the minimum (Min), the maximum (Max), the arithmetic average (AM), geometric mean (GM), and the annual effective doses equivalent (E_{AEDE}) obtained.

Table 3.1: Summary of indoor radon concentration levels in the surveyed regions, and its annual equivalent effective doses.

(E_{AEDE}) (mSv/y)	**Indoor Radon Concentration levels (C_{Rn})(Bq/m^3)**					**Main Zone**
	GM	**AM**	**Max**	**Min**	**N**	
0.6	26.96	34.54	131.6	11.8	15	**Al-Oroq**

1.295	52.65	74.9	245.02	20.98	24	**Down town**
1.38	54.77	79.68	322.84	9.69	23	**Wadi Jdoor**
1.22	51.77	70.55	223.99	13.22	42	**Al-Matiana**
2.08	55.169	120.26	857.05	12.82	19	**Al-Baqa'a**
1.005	42.5	58.26	176.67	6.29	15	**Al-Zaher**

In the following subsections, the results of each sector will be discussed in details and independently. It is worth mentioning here that the coded appeared in tables and figures in the following subsections represent the floors and dwellings numbers. For example, bedroom (1) is used to represent bedroom in the first floor of the inspected building number 1 as indicated in the tables; while the numbers to the right of figures represent the building numbers.

3.5.1 Al-Oroq Region:

In this region, five houses were selected randomly and a total number of 15 detectors have been collected and analyzed. In each dwelling, there are 4 detectors distributed inside the dwelling in (living room, bed room, bathroom, and kitchen) to monitor the indoor radon concentration levels and one detector placed outside the dwelling to monitor the outdoor concentration levels. The results of indoor radon concentration levels for Al-Oroq dwellings are calculated using equation (3.4) and exhibited in Table (3.2) and Fig. (3.1). The equivalent annual effective doses for the data in Table (3.2) are calculated using equation (3.5) and the results are shown in Table (3.3).

Table 3.2: Indoor radon concentration levels in Al-Oroq dwellings.

Indoor radon concentration levels (C_{Rn}) (Bq/m^3)						**Buildings**
Outdoor	**Bathroom**	**Kitchen**	**Living room**	**Bedroom**		
---	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 2**	**Floor 1**	
---	17.7	45.1	15.9	28.7	34.4	**1**
---	---	11.9	16.5	---	---	**2**
---	131.6	---	---	---	---	**3**

---	---	37.4	16.2	---	25.6	**4**
10.3	---	17.9	66.1	---	11.8	**5**
---	**74.7**	**28.1**	**28.7**	**28.7**	**23.9**	**AM**
---	**48.4**	**24.5**	**23**	**28.7**	**21.8**	**GM**
---	17.7	11.9	15.9	---	11.8	**Min**
---	131.6	45.1	66.1	---	34.4	**Max**

Table 3.3: Annual effective doses equivalent in Al-Oroq dwellings.

Annual effective dose equivalent (E_{AEDE}) (mSv/y)						**Buildings**
Outdoor	**Bathroom**	**Kitchen**	**Living room**	**Bedroom**		
---	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 2**	**Floor 1**	
---	0.31	0.78	0.27	0.50	0.59	**1**
---	---	0.21	0.28	---	---	**2**
---	2.28	---	---	---	---	**3**
---	---	0.65	0.28	---	0.44	**4**
0.19	---	0.31	1.14	---	0.20	**5**
---	**1.3**	**0.49**	**0.49**	**0.50**	**0.41**	**AM**
---	**0.84**	**0.43**	**0.39**	**0.50**	**0.37**	**GM**
---	0.31	0.21	0.27	---	0.20	**Min**
---	2.28	0.78	1.14	---	0.59	**Max**

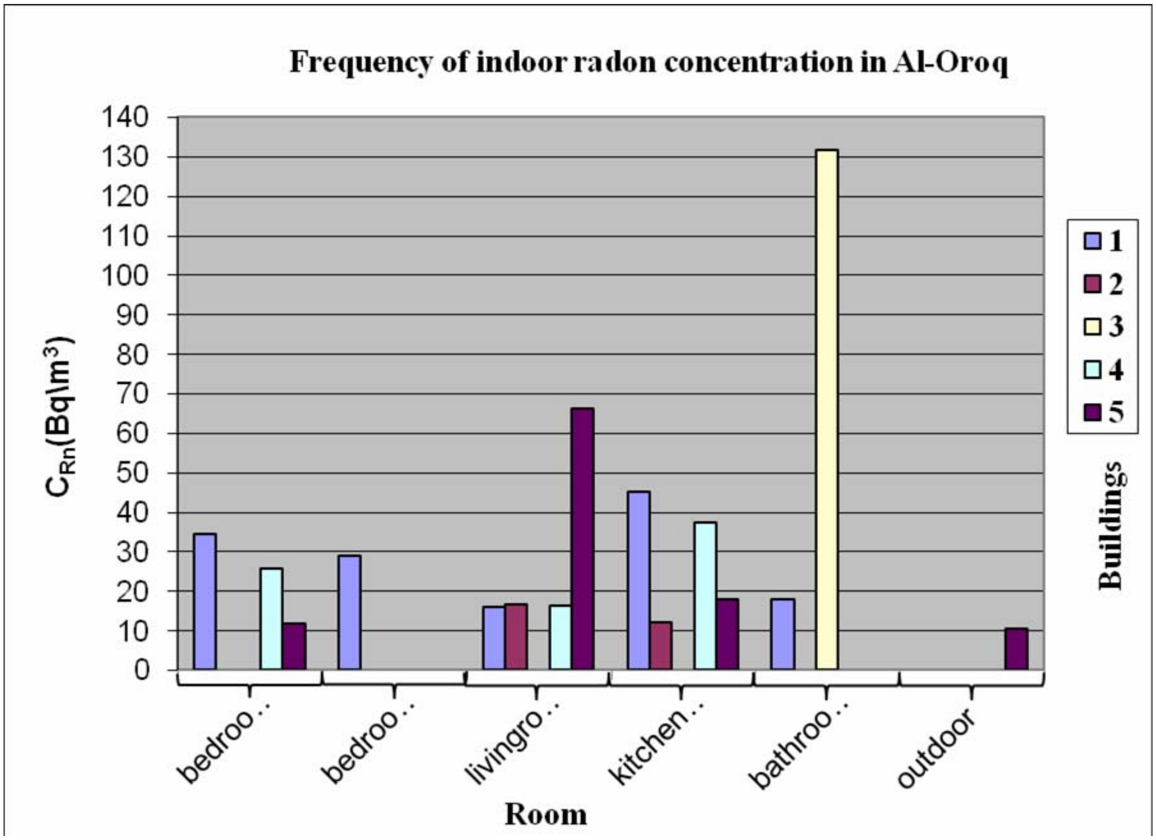

Figure 3.1: The radon concentration levels in Al-Oroq dwellings.

The concentration levels in the first building are slightly higher than the obtained results for other buildings, except in the living rooms and the bathrooms of 2,3,4, and 5 buildings. This is because ventilation rates in the old buildings are much poorer than that of the new buildings. Moreover, old buildings have too many cracks in the floors and walls that allow radon gas to emanate easily from soil, ground, and building materials into the indoor dwelling at this is resulted in an increase of the radon gas concentration. Another interesting note is that the new buildings rooms and kitchens are spacious and well ventilated, and their walls and ceilings are well painted and having almost no cracks.

The radon concentration level in bathrooms are found to vary between 17.7 and 131.6 Bq/m^3. The highest value of 131.6 Bq/m^3 was found in a bathroom in the first floor of the third building. This high value might be attributed to bad ventilations where the bathroom has no windows. We believe that the raw materials used in paving the bath such as ceramic, granite and paintings plays a vital role in having such high values (Dabayneh, 2008). In other words, we believe that the used raw materials might contain some radioactive materials.

The radon concentration levels in bedrooms vary from 11.8 Bq/m^3 to 34.4Bq/m^3. In the first house, the average concentration levels in the first floor are higher than that of the second floor. This is an indication that radon concentration levels are affected by elevation, where ventilation in higher floors such as the second floor are much better than that of lower floors as in the first floor. The average value of radon concentration levels in living rooms are found to vary between 15.9 and 66.1 Bq/m^3. The kitchens have average radon concentrations between 11.9 Bq/m^3 to 45.1 Bq/m^3.

Relatively speaking, the concentration levels in bathrooms are found to be higher than in kitchens, living room and bedroom. Also, the radon concentration levels in kitchens are higher than of the living room. This might be due to the frequent use of living rooms (more than 10 hours a day) and to the raw material used in kitchens such as ceramic and granite (Dabayneh ,2008). The concentration levels in the second floor bedrooms are less than that of the first floor. This is because ventilation in the second floor is much better than that of the first floor.

All the calculated radon concentration levels in this region (Al-Oroq) are below the international adopted standard levels. The calculated annual effective doses in this region are slightly lower than the average annual effective dose limit of 1.3 mSv/y assigned by Environmental Protection Agency (EPA) (Farid, 1992; ICRP, 1994a), except in the bathroom located in the first floor within the third house.

3.5.2 Down Town Region:

In this region, four houses were selected randomly and the total number of collected detectors in this region is 24 detectors. The radon concentration levels in the living rooms, kitchens, bedrooms, bathrooms, and storages for dwellings are calculated and tabulated in Table (3.4) and shown in Fig. (3.2). The obtained data were used to estimate an approximated annual the effective doses equivalent in these dwellings and tabulated in Table (3.5).

Table 3.4: Indoor radon concentration levels in down town dwellings.

Indoor radon concentration levels (C_{Rn}) (Bq/m^3)							Buildings
Outdoor	**Storage**		**Bathroom**	**Kitchen**	**Living room**	**Bedroom**	
---	**Floor 2**	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 1**	
61.75	---	---	70.46	149.33	86.23	157.74	**6**
13.44	---	22.63	49.97	20.98	23.81	26.16	**7**
80.4	---	245.02	149.33	132.50	114.62	87.28	**8**
65.20	64.15	168.25	114.62	153.53	104.11	69.41	**9**
55.2	**---**	**145.3**	**96.10**	**114.09**	**82.19**	**85.15**	**AM**
45.7	**---**	**97.7**	**88.11**	**89.35**	**70.35**	**70.71**	**GM**
13.44	---	22.63	49.97	20.98	23.81	26.16	**Min**
80.4	---	245.02	149.33	153.53	114.62	157.74	**Max**

Table 3.5: Annual effective dose equivalent in down town dwellings.

Annual effective dose equivalent (E_{AEDE}) (mSv/y)							Buildings
Outdoor	**Storage**		**Bathroom**	**Kitchen**	**Living room**	**Bedroom**	
---	**Floor 2**	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 1**	
1.1	---	---	1.22	2.58	1.5	2.73	**6**
0.23	---	0.39	0.86	0.36	0.41	0.45	**7**
1.40	---	4.24	2.58	2.29	2	1.51	**8**
1.13	1.11	2.91	1.98	2.66	1.98	1.2	**9**
0.965	**---**	**2.5**	**1.66**	**1.97**	**1.42**	**1.47**	**AM**
0.795	**---**	**1.69**	**1.52**	**1.54**	**1.21**	**1.22**	**GM**
0.23	---	0.39	0.86	0.36	0.41	0.45	**Min**
1.40	---	4.24	2.58	2.66	1.98	2.73	**Max**

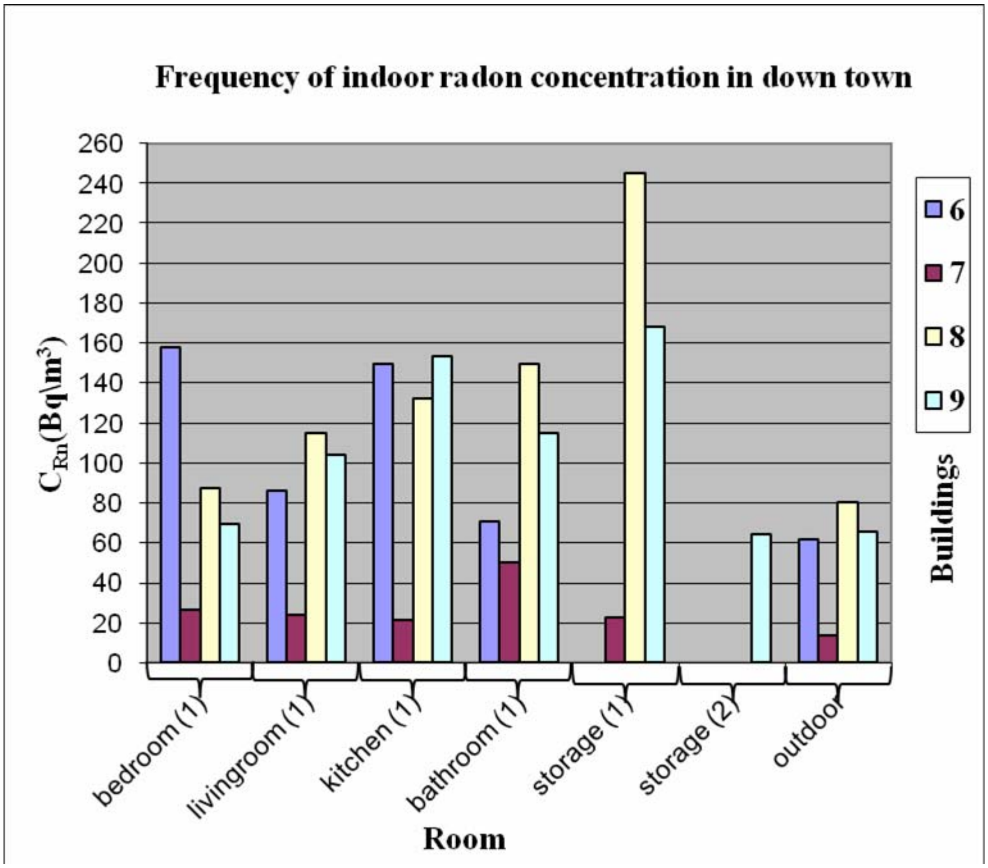

Figure 3.2: The radon concentration levels in down town dwellings.

The indoor radon concentration levels obtained from detectors distributed in bedrooms are found to vary between 26.16 to 157.74 Bq/m^3. The highest value (157.74 Bq/m^3) is reported in a bedroom in building number 6, which is a new building but it is closed most of the time (not in use). The concentration levels in living rooms vary between 23.81 to 114.62 Bq/m^3. The highest value of 114.62 Bq/m^3 was found in a living room in building number 8, which is an old building, having bad ventilation and contains cracks in walls.

The results of radon concentration in kitchens vary from 20.98 to 153.53 Bq/m^3. We believe that the high radon concentration levels were attributed to poor ventilation, cooking gas, heating and raw building materials uses (such as ceramic, granite, etc..) (Dabayneh, 2008).

In bathrooms, the average radon concentration levels are varying between 49.97 to 149.33 Bq/m^3.

The storage rooms in houses 8 and 9 were found to have radon concentration levels between 245.02 and 168.25 Bq/m^3, respectively. Those concentration levels are higher than other results obtained for other rooms in this region and higher than the USA assigned levels. The reason for having higher values is because these rooms are almost closed of the time and small. So, air interchange between indoor and outdoor is minimal. Hence radon might be accumulated and resulted in an increase of radon levels inside these rooms.

In this region, the minimum average concentrations radon is found in building 7 where the building ventilation is very well. This result reflects the effect of good ventilations and enough separation distance between the building and it surrounding buildings (which affects the renewable of air continuously) in decreasing the radon concentration levels.
In general, the average of indoor radon concentration levels in down town dwellings is lower than 200 Bq/m^3 (see Table (3.4)). This value is below the international assigned safe limits of 200-600 Bq/m^3 by ICRP (ICRP,1994a).

3.5.3 Wadi Jdoor Region:

The estimated average radon concentration levels in this region are obtained from 23 dosimeters distributed in six dwellings. The obtained results are summarized in Table (3.6) and shown in Fig. (3.3). The annual effective doses for each data are also calculated and summarized in Table (3.7).
In this region, the radon concentration levels in bedrooms are found to be higher than that in kitchens, living rooms and bathrooms, respectively, except in building number 10 (see Table (3.6)). The high radon concentration levels inside bedrooms might be due to the relatively poor ventilation since these rooms are closed most of the time.
The concentration radon levels of living rooms in first floor vary from 23.77 Bq/m^3 to 105.16 Bq/m^3.

In general, the radon concentration levels were found to decrease with the floor level, as indicated in the house number 15. This is because ventilation in the second floor is much better than that of the first floor. Also, this building has the highest concentration levels among all other buildings in this region. This is due to bad ventilation and the separation distance between this building and other buildings is about 2 m, which is not good enough air to exchange between inside and outside. This reflects the importance of having a space between buildings in order to have good ventilation.

Table 3.6: Indoor radon concentration levels in Wadi Jdoor dwellings.

Indoor radon concentration levels (C_{Rn}) (Bq/m^3)									**Buildings**
Outdoor	**Storage**	**Bathroom**		**Kitchen**	**Livingroom**		**Bedroom**		
---	**Floor 1**	**Floor 2**	**Floor 1**	**Floor 1**	**Floor2**	**Floor 1**	**Floor 2**	**Floor 1**	
---	---	---	22.62	9.69	---	---	---	19.88	**10**
20.11	---	---	23.25	25.60	---	23.77	---	56.42	**11**
12.0	---	---	13.32	36.31	---	---	---	---	**12**
28.21	---	---	---	---	---	48.85	---	---	**13**
---	---	---	---	---	---	---	---	26.12	**14**
36.4	127.24	79.92	107.26	167.20	79.92	105.16	112.52	322.84	**15**
24.18	**---**	**---**	**41.6**	**59.70**	**---**	**50.85**	**---**	**106.3**	**AM**
22.3	**---**	**---**	**29.44**	**35.03**	**---**	**49.6**	**---**	**55.46**	**GM**
12.0	---	---	13.32	9.69	---	23.77	---	19.88	**Min**
36.4	---	---	107.26	167.20	---	105.16	---	322.84	**Max**

Table 3.7: Annual effective dose equivalent in Wadi Jdoor dwellings.

annual effective dose equivalent (E_{AEDE}) (mSv/y)									**Buildings**
Outdoor	**Storage**	**Bathroom**		**Kitchen**	**Livingroom**		**Bedroom**		
---	**Floor 1**	**Floor 2**	**Floor 1**	**Floor 1**	**Floor2**	**Floor 1**	**Floor 2**	**Floor 1**	
	---	---	0.39	0.17	---	---	---	0.34	**10**
0.35	---	---	0.4	0.44	---	0.41	---	0.98	**11**
0.2	---	---	0.23	0.63	---	---	---	---	**12**
0.49	---	---	---	---	---	0.85	---	---	**13**
---	---	---	---	---	---	---	---	0.45	**14**
0.63	2.2	1.38	1.86	2.89	1.38	1.82	1.95	5.59	**15**
0.42	**---**	**--**	**0.72**	**1.03**	**---**	**1.03**	**---**	**1.84**	**AM**
0.83	**---**	**---**	**0.50**	**0.61**	**---**	**0.86**	**---**	**0.96**	**GM**
0.2	---	---	0.23	0.17	---	0.41	---	0.34	**Min**
0.63	---	---	1.86	2.89	---	1.82	---	5.59	**Max**

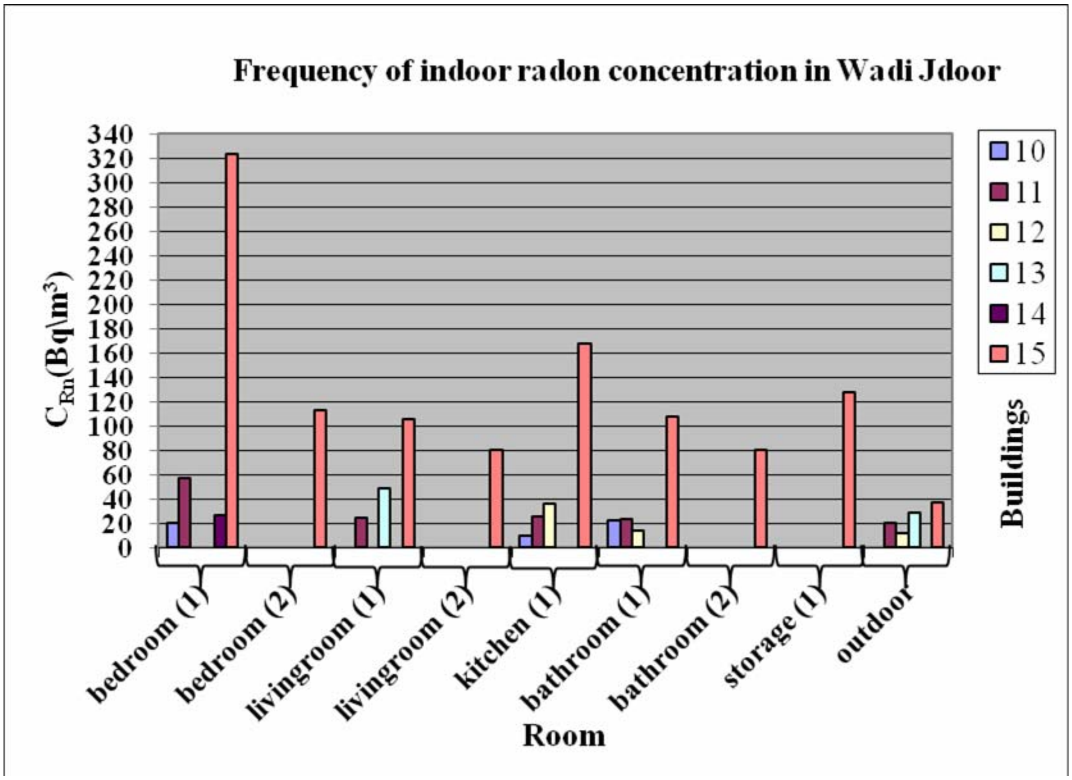

Figure 3.3: The radon concentration levels in Wadi Jdoor dwellings.

The differences in concentration levels between the buildings data are attributed to the type of soil, building age, ventilation, and also to raw materials.

3.5.4 AL-Matiana Region:

The obtained results of the average radon concentration levels for 42 detectors collected from 11 dwellings in AL-Matiana region are listed in Table (3.8) and shown in Fig.(3.4). Besides, the annual effective doses for the obtained concentration levels are calculated and inserted in Table (3.9).

The radon concentration levels in bedrooms in this region are varying between 21.87 and 224 Bq/m^3. The maximum reported value of 224 Bq/m^3 belonging to a bedroom in the first floor of the old building number 24.

In living rooms, the highest reported value of concentration levels is 159.84 Bq/m^3 in a living room in building number 25; while the lowest value of 20.51 Bq/m^3 is reported in building 19. The concentration levels of radon in the first floor of building number 21 are higher than those belong to the second floor. This is an indication of good ventilation as you go from lower to higher floors. The variations of concentration levels are due to amount of ventilation, age of dwellings and raw materials used in constructions. It should be noted, there is a large variation in the radon concentrations within the same building due to ventilation, raw material used. Indoor radon concentrations are typically higher than the outdoor concentration levels (see Tables 3.2, 3.4, 3.6, 3.8) .

Table 3.8: Indoor radon concentration levels in AL-Matiana dwellings.

Indoor radon concentration levels (C_{Rn}) (Bq/m^3)								**Buildings**
Outdoor	**Storage**	**Bathroom**	**kitchen**	**Living room**		**Bedroom**		
---	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 2**	**Floor 1**	**Floor 2**	**Floor 1**	
8.79	41.26	26.85	21.48	---	---	---	22.46	**16**
---	---	18.00	---	---	29.39	---	21.87	**17**
---	---	13.22	30.99	---	59.01	---	33.95	**18**
---	---	---	25.97	---	20.51	---	26.20	**19**
---	---	---	---	---	34.43	---	---	**20**
14.10	---	---	---	14.10	33.83	41.52	79.46	**21**
14.34	---	---	19.77	---	---	---	---	**22**
86.7	130.40	89.39	---	---	152.48	---	102.00	**23**
52.58	---	86.23	71.51	---	117.78	---	224.00	**24**
---	---	95.69	109.37	---	159.84	---	63.10	**25**
77.82	---	85.18	184.03	---	145.12	---	86.23	**26**

42.39	**85.83**	**59.22**	**66.16**	**---**	**83.6**	**---**	**73.25**	**AM**
29.28	**73.35**	**45.46**	**46.80**	**---**	**63.69**	**---**	**54.6**	**GM**
8.79	41.26	13.22	19.77	---	20.51	---	21.87	**Min**
86.7	130.40	95.69	184.03	---	159.84	---	224.00	**Max**

Table 3.9: Annual effective dose equivalent in AL-Matiana dwellings.

Annual effective dose equivalent (E_{AEDE}) (mSv/y)								**Buildings**
Outdoor	**Storage**	**Bathroom**	**kitchen**	**Livingroom**		**Bedroom**		
---	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 2**	**Floor 1**	**Floor 2**	**Floor 1**	
0.15	0.71	0.46	0.37	---	---	---	0.39	**16**
---	---	0.31		---	0.51	---	0.38	**17**
---	---	0.23	0.54	---	1.02	---	0.59	**18**
---	---	---	0.45	---	0.35	---	0.45	**19**
---	---	---	---	---	0.6	---	---	**20**
0.24	---	---	---	0.24	0.59	0.72	1.37	**21**
0.25	---	---	0.34	---	---	---	---	**22**
1.5	2.26	1.55	---	---	2.64	---	1.76	**23**
0.91	---	1.49	1.24	---	2.04	---	3.88	**24**
---	---	1.66	1.89	---	2.77	---	1.09	**25**
1.35	---	1.47	3.18	---	2.51	---	1.49	**26**
0.73	**1.49**	**1.02**	**1.14**	**---**	**1.45**	**---**	**1.27**	**AM**
0.50	**1.27**	**0.79**	**0.81**	**---**	**1.10**	**---**	**0.94**	**GM**
0.15	0.71	0.23	0.34	---	0.35	---	0.38	**Min**
1.35	2.26	1.66	3.18	---	2.77	---	3.88	**Max**

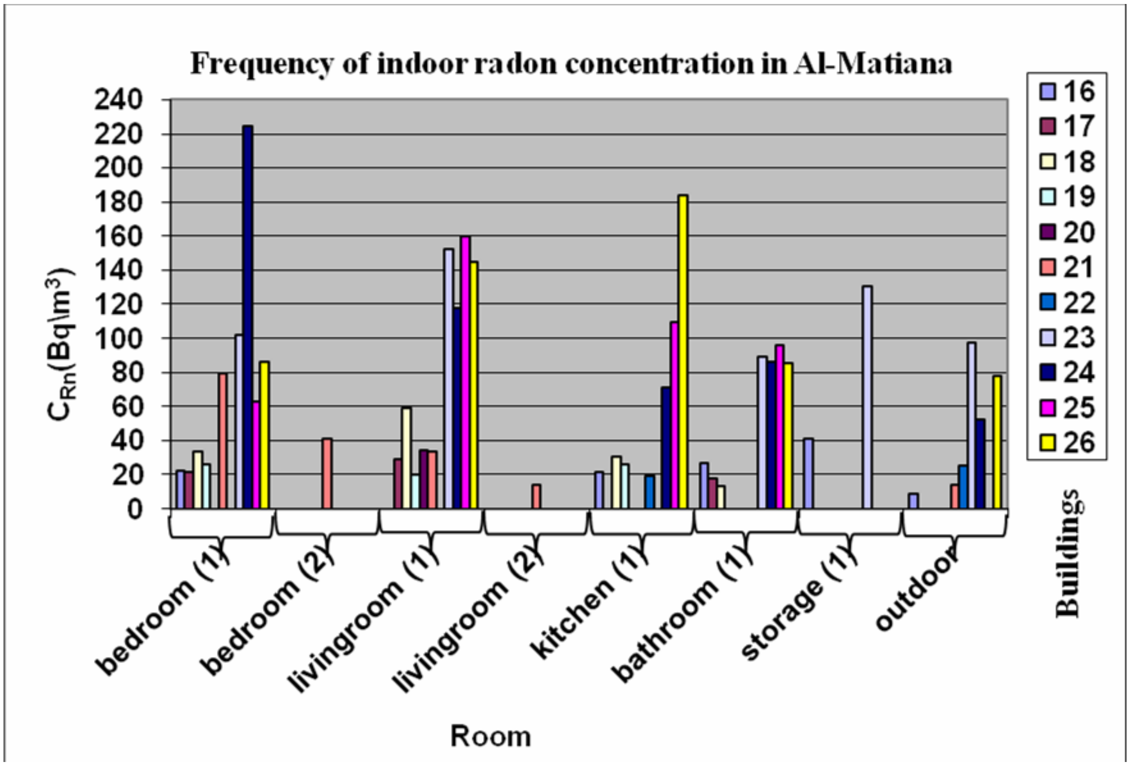

Figure 3.4: The radon concentration levels in AL-Matiana dwellings.

3.5.5 Al-Baqa‘a Region:

In Al-Baqa‘a region, a total number of 19 detectors are collected from the distributed dosimeters in five houses selected randomly in this region. The obtained indoor radon concentration levels results from these detectors are exhibited in Table (3.10) and Fig. (3.5). The annual effective does equivalent are calculated from the data exhibited in Table (3.10) and the results are shown in Table (3.11).

Table 3.10: Indoor radon concentration levels in Al-Baqa‘a dwellings.

Indoor radon concentration levels (C_{Rn}) (Bq/m^3)						Buildings
Outdoor	**Storage**	**Bathroom**	**Kitchen**	**Livingroom**	**Bedroom**	
---	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 1**	
84.13	92.54	857.05	208.22	95.69	124.09	**27**

89.39	---	118.83	179.82	98.85	284.98	**28**
11.9	---	12.82	---	24.35	23.33	**29**
14.08	---	---	---	20.01	---	**30**
---	---	---	22.76	19.01	---	**31**
49.88	**---**	**329.57**	**136.93**	**51.58**	**144.13**	**AM**
33.50	**---**	**109.30**	**94.81**	**38.77**	**93.79**	**GM**
11.9	---	12.82	22.76	20.01	23.33	**Min**
89.39	---	857.05	208.22	98.85	284.98	**Max**

The radon concentration levels recorded for this region are found to vary from 12.82 Bq/m^3, (found in a bathroom in building 29), to 857.05 Bq/m^3 (found in a bathroom in building 27). This might be attributed to bad ventilations since the bathroom in building 27 have no windows, thus it has no ventilations at all. Also, the raw materials used in this bathroom are ceramic and granite and paintings might produce such high values (Dabayneh, 2008).

The obtained radon concentration levels in this region indicate that the radon concentration levels in bedrooms are in between 23.33 to 284.98 Bq/m^3. The maximum recorded value is in a bedroom in the first floor of building number 28, which is an old building composed of a single floor (or the ground floor). This building is characterized by bad ventilation and cracked walls.

The radon concentration levels in living rooms vary between 19.01 and 98.85 Bq/m^3. The highest value of concentration in kitchens is 208.22 Bq/m^3 and the lowest value is 22.76 Bq/m^3. The highest value was found in the kitchen in the first floor of building 28, which has bad ventilation.

Generally speaking, the low concentration levels are attributed to good ventilation, and raw material used in the constructed buildings (Dabayneh, 2008).

The radon outdoor concentration levels they are lower than the indoor level values (see Table (3.10)). It was found that the average indoor radon concentration levels in AL-Baqa‘a dwellings is 165.6 Bq/m^3, while the outdoor radon concentration levels is 49.88 Bq/m^3.

Table 3.11: Annual effective dose equivalent in Al-Baqa‘a dwellings.

Annual effective dose equivalent (E_{AEDE}) (mSv/y)						Buildings
Outdoor	**Storage**	**Bathroom**	**Kitchen**	**Livingroom**	**Bedroom**	
---	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 1**	**Floor 1**	
1.5	1.6	14.83	3.60	1.7	2.15	**27**
1.55	---	2.06	3.11	1.71	4.93	**28**
0.2	---	0.22	---	0.4	0.4	**29**
0.24	---	---	---	0.4	---	**30**
---	---	---	0.4	0.35	---	**31**
0.87	**---**	**5.70**	**2.37**	**0.89**	**2.49**	**AM**
0.58	**---**	**1.89**	**1.63**	**0.67**	**1.62**	**GM**
0.20	---	0.22	0.4	0.35	0.4	**Min**
1.55	---	14.83	3.60	1.71	4.93	**Max**

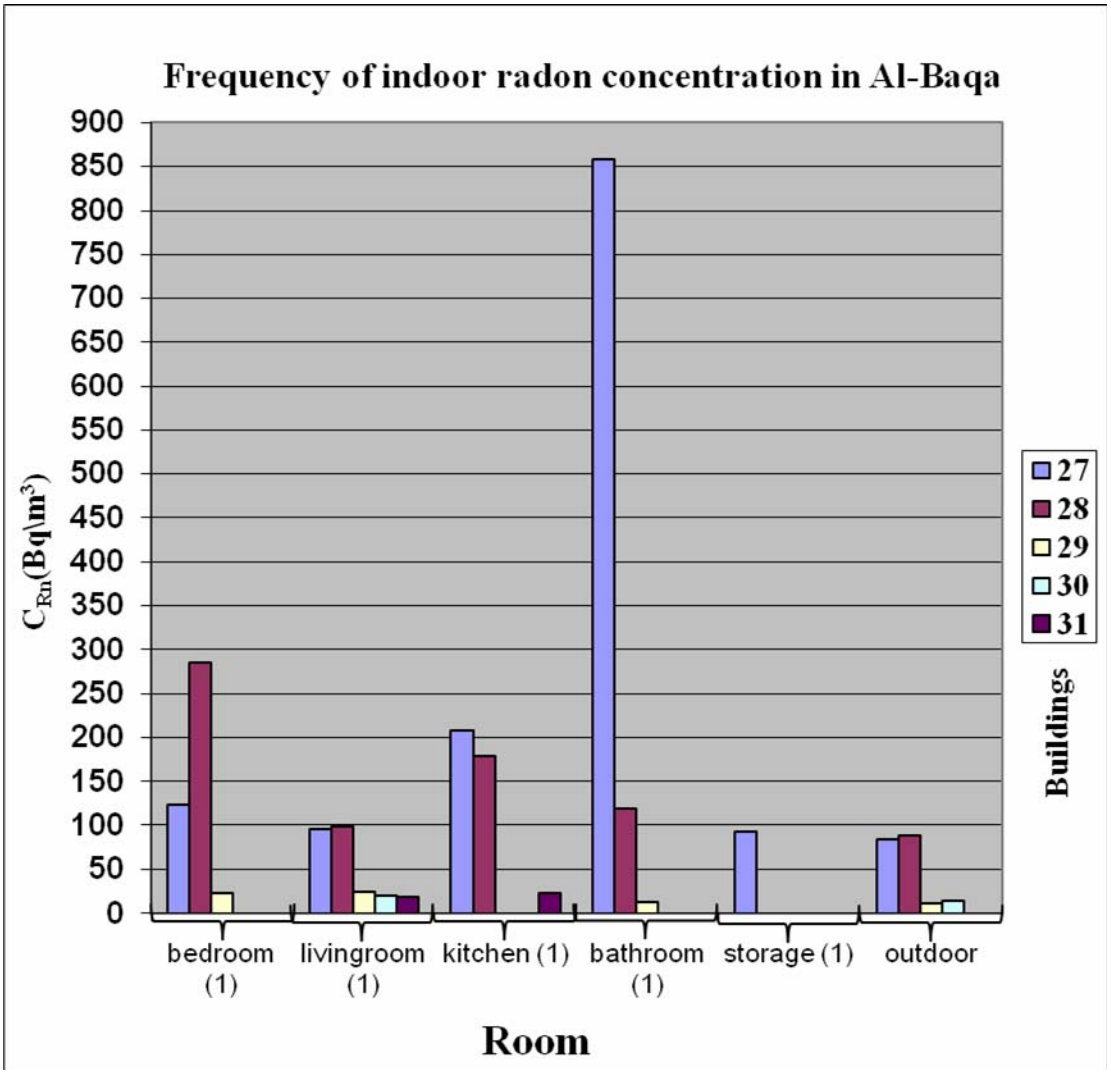

Figure 3.5: The radon concentration levels in Al-Baqa'a dwellings.

3.5.6 Al-Zaher Region:

The indoor radon concentration levels and the annual effective dose equivalent for 15 detectors collected from 4 buildings in this region are estimated and inserted in Tables (3.12) and (3.13) and shown in Fig. (3.6).

The radon concentration levels in this region are found to be lower than 150 Bq/m^3, except in the bedroom in building number 32. This is because the building is an old one composed of only a ground floor that has poor ventilation.

Table 3.12: Indoor radon concentration levels in Al-Zaher dwellings.

Indoor radon concentration levels (C_{Rn}) (Bq/m^3)						Buildings
Outdoor	Bathroom	Kitchen		Livingroom	Bedroom	
---	Floor 1	Floor 2	Floor 1	Floor 1	Floor 1	
39.96	53.63	---	93.59	90.44	176.67	**32**
6.12	---	6.29	14.34	25.16	25.66	**33**
---	---	---	---	42.94	38.36	**34**
12.1	---	---	14.77	30.31	---	**35**
19.39	**---**	**---**	**40.9**	**47.21**	**80.23**	**AM**
14.36	**---**	**---**	**27.06**	**41.48**	**55.82**	**GM**
6.12	---	---	14.34	25.16	25.66	**Min**
39.96	---	---	93.59	90.44	176.67	**Max**

Table 3.13: Annual effective dose equivalent in Al-Zaher dwellings.

Annual effective dose equivalent (E_{AEDE}) (mSv/y)						Buildings
Outdoor	Bathroom	Kitchen		Livingroom	Bedroom	
---	Floor 1	Floor 2	Floor 1	Floor 1	Floor 1	
0.7	0.93	---	1.62	1.6	3.1	**32**
0.1	---	0.11	0.25	0.4	0.4	**33**
---	---	---	---	0.7	0.7	**34**
0.21	---	---	0.26	0.5	---	**35**
0.34	**---**	**---**	**0.71**	**0.82**	**1.39**	**AM**
0.24	**---**	**---**	**0.47**	**0.72**	**0.96**	**GM**
0.1	---	---	0.25	0.44	0.44	**Min**
0.7	---	---	1.62	1.56	3.06	**Max**

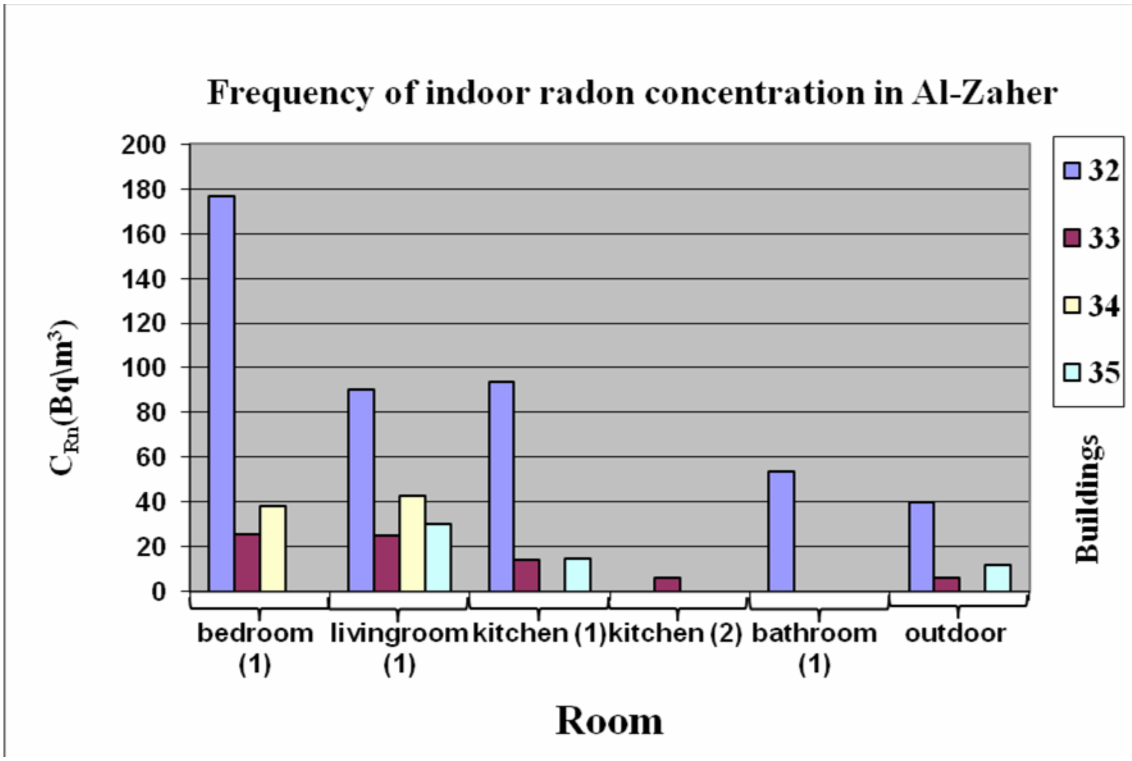

Figure 3.6: The radon concentration levels in Al-Zaher dwellings.

The results of radon concentration levels in this region exhibit that bedrooms have the highest values among all rooms and their values are varying between 25.66 to 176.67 Bq/m^3. The lowest values, in this region, are reported in kitchens and they were varying between 14.34 to 93.59 Bq/m^3 in first floor (ground floor). In the second floor, a radon level of 6.29 Bq/m^3 was reported in a kitchen in building 33, floor 2.

The indoor radon concentration levels are higher than that found for outdoor values (see Table (3.12)).

The obtained radon levels are less than the international assigned values and recommended in the USA, ICRPA ,and WHO (Gonzalez, 1993; ICRP, 1994a; WHO, 2001). Hence, no recommendations had been made in this region.

Chapter Four

Discussion, Conclusion and Future work

4.1 Introduction

4.2 Discussion

4.3 Recommendations

4.3.1 Remove the Sources

4.3.2 Protective Deeds

4.3.3 Ventilation

4.3.4 Quit the Smoking Inside Dwellings

4.4 Conclusion

4.5 Future Work

Chapter Four

Discussion, Conclusion and Future work

4.1 Introduction

In this chapter, we shall discuss the general features of radon concentration levels in Sourif inspected dwellings. Beside on this dissection, we have several recommendation drawn from our discussions. By the end of this chapter, we shall address some problems for further investigation and studies.

4.2 Discussion

In this study, the Solid State Nuclear Track Detectors (SSNTDs) type (CR-39) are used to estimate the average radon concentration levels and the annual effective dose equivalent in 35 dwellings in Sourif city.

The average indoor radon concentration levels in AL-Oroq, Down Town, Wadi Jdoor, AL-Matiana AL-Baqa'a and AL-Zaher, are respectively: 34.54, 74.9, 79.68, 70.55, 120.25 and 58.26 Bq/m^3. The mean values of radon concentrations in bathrooms, storages, bedrooms, kitchens and living rooms are 104.96, 103.01, 78.24, 64.6, and 54.77 Bq/m^3, respectively; while the mean values of the annual effective dose equivalent are 1.8, 1.78, 1.35, 1.11and 0.95 mSv/y. The range of radon concentration levels and the corresponding frequency are listed in Table (4.1) and shown in Fig. (4.1).

Table 4.1: Range and frequency of radon concentration levels for the selected dwellings from the monitored zones.

%100	Frequency	Range of radon concentration (Bq/m^3)
53.62	74	(0-50)
22.460	31	(50-100)
13.040	18	(100-150)
6.52	9	(150-200)
4.35	6	above 200

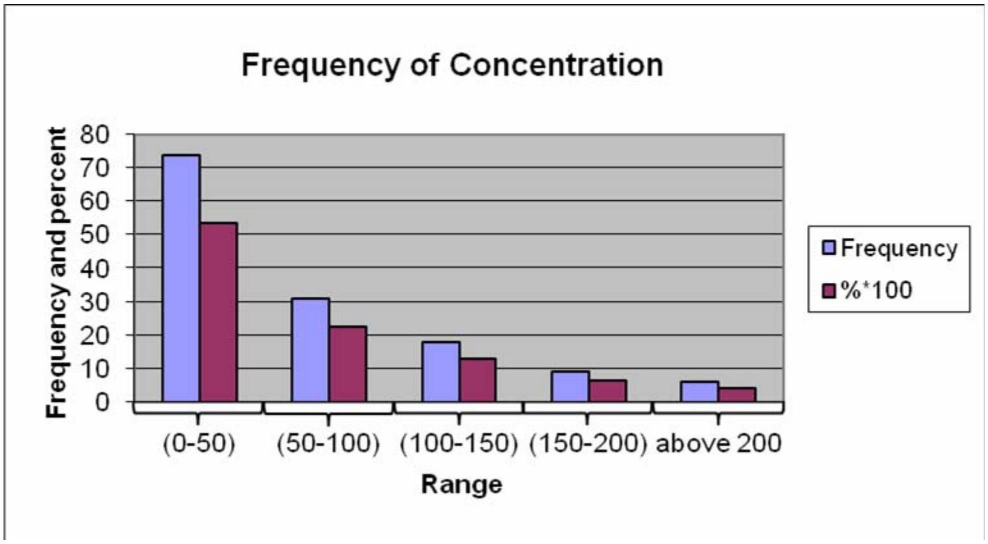

Figure 4.1: Frequency of radon concentration levels in Sourif dwellings.

The calculated indoor radon concentration levels are found to be within the international assigned standard levels (WHO, 2001) except in less than 10.87% of the inspected dwellings. According to the statistical analysis in Table (4.1), the mean indoor radon concentrations were found to be below 150 Bq/m^3 in more than 89.13% of the inspected dwellings. In less than 10.87% of dwellings, the radon concentration exceeds the 150 and above 200 Bq/m^3 which is considered to be the safe values recommended by USA and EPA. In just only six locations, the obtained data exceed the safe assigned concentration levels of 200 Bq/m^3 (ICRP, 1994a; Popovic, *et al.,* 1996; EPA, 2002). Hence, no recommendations for mitigations had been made. However, individual advises have been made to building owners whose houses were found to have high levels (a above 200 Bq/m^3). The advice is basically based on increasing the ventilation rates, frequent use of their facilities.

The differences of concentration levels between the inspected buildings are generally attributed to geological characteristics of soil, building age, and to raw materials.
There are large differences between the arithmetic mean and the geometric mean. The percentage differences varying between 40% to 95%. This is because some dwellings have high radon levels concentration; while others have low concentration levels.

We believe that the inspected region has no radon pollution at all, except in some buildings where radon concentration levels can be fixed by improving ventilations. In addition, the used raw materials might have different sources and different ingredients. That might reflect that in some cheap painting ingredients have material rich in radon resources (Dabayneh, 2008).

4.3 Recommendations

By the end of this work, several recommendations can be drawn from the study and they might be taken into considerations. Among, there are four basically recommendations that should be implemented to minimize the high radon concentration levels and their harm effect on humans reported in some inspected facilities in some buildings. The recommendations are as follows:

4.3.1 Remove the Sources:

It is intended to get rid of materials containing uranium in the residential environment. It is worth mentioning that Palestinian dwellings are constructed using local granite stones (Yatta, Sa'eer, ect..) and such stones are rich with uranium element. The presence of uranium in the top layer of soil, or in groundwater resources will influence the radon concentration levels.

In some cheap building materials painting have some compile that might emit radon gas. The solution to address the problem of radioactive contamination, is a radical solution to make sure that no risks to be produced in the future.

4.3.2 Protective Deeds:

In this case we focused on preventing the radon emission from being entering the buildings. This can be directly by placing non-permeable insulation or by converting the flow of gas to outside the building by introducing certain infra structure for that.

4.3.3 Ventilation:

It is axiomatic that no mixing of air inside the house air, and lead to an increase of the radon concentration levels. Generally, ventilation lead to a low concentration of this gas, by allowing the exchange of air inside the house. This keeps the house air pure and radon concentration in its lowest possible level.

4.3.4 Quit the Smoking Inside Dwellings:

Smoke in closed places has the same effect as dust. Radon gas molecules attach themselves to the smoke particles in air and enter the human body to the lung during the breathing processes. As radon inside lungs, it may decay into ^{218}Po and alpha particles. The alpha particles loose energy to lug tissue and this produce damage to the lungs tissue and cell. Therefore there is a big possibility to have a lung cancer.

4.4 Conclusion

Any differences and variations between bathrooms and the rest of the apartments were explained on the basis of bad ventilation and construction raw materials such as ceramic, granite**.**

The radon concentration values in the first floors were higher than those in the upper floors, and the old building values are also higher than the newly constructed buildings.
The resulted differences between the minimum and maximum concentration levels in the inspected regions and their variations are might be due to the ventilation, geological characteristics of soil, and the types of building materials such as concrete, gypsum, stone ceramic and cement(Dabayneh, 2008), are also influence the radon concentration levels.

The obtained results for the indoor ^{222}Rn concentration levels in this part of Palestine indicate that this region can be classified as a low radon concentration levels.

We hope this study will pave the way to measure the radon concentration levels in other cities and to draw a radioactive radon map for the Palestine.

4.4 Future work

The study should be extended to include different places and testing other parameters that might affect the radon concentrations. This include investigating raw materials such as local granite stones, paintings, water sources, soil, and construction styles.

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Appendices

Gallery of the Investigated Dwellings.

Appendices:

Appendix A

Gallery of the Investigation Dwellings in this Study

1 - A house was built of cement, a two-floor, it has a good ventilations. The distance between it and other houses approximately 7 meters. It has been built 40 years age.

2 - A house was built of cement and consists of two floors, has good ventilation. It has been built since 2005 .

3 - A house was built of cement, it is ground floor, it has a bad ventilation. The separation distance is about 1.5 m. It has been built since 1990 years.

4 - A house was built of stones, ground floor. It has a good ventilation, the distance between it and other houses about 5 meters. It has been built since 1995.

5 - A house was built of stone and consists of two floors . It has a good ventilation .The distance between it and other houses around 10 meters. It has been built 10 years ago.

6 - A is house built from cement and stones, contains the cracks in the walls and has a bad ventilation. The separation distance between it and other houses approximately 5 meters. It has been built 50 years ago.

7 - A house was built from cement , stones and local granite. It is one floor, the separation distance between it and other houses is 10 meters . It has been built since 2000.

8 - A house was built from cement. It is ground floor, contains cracks in wall and has a bad ventilation. It has been built 35 years ago.

9 - A house was built from stones and cement, it consists of two floors, the distance between it and other houses almost 10 m. It has been built since 1990 years.

10 - A house was built from stones and cement, consists of one floor. It has a good ventilation. It has been built since 1994.

11 - A house was built from cement, consists of one floor and has a good ventilation. The separation distance between it and other houses almost 6 meters. It has been built since 2003.

12 - A house was built from cement , consisting of two floors. The distance between it and other houses approximately 4 meters. It has been built since 2005.

13 - A house was built from stones and cement. It consists of one floor, and has a good ventilation. It has been built since 1989.

14 - Ahouse was built from cement, contain of one floor. It has a good ventilation . It has been built since 1985.

15 - A house was built from stones and cement consists of three floors. but it has a bad ventilation . It has been built since 1987. The separation distances is about 2 m .

16 - This house was built from stones and cement consisting of two floor. It has a good ventilation .The distance between it and other houses about 10 meters. It has been built since 1990.

17 - A house was built from cement, consisting of two floors. It has a good ventilation. The separation distance is 10 meters. It has been built 7 years ago.

18 - A houses was built from stones and cement, consisting of two floors. It has a good ventilation. The separation distance 10 meters. It has been built since 1984.

19 - A house was built from stones and cement. It consisting of two floors, and has a good ventilation. It has been built 25 years ago.

20 - A house was built from cement. It is containing of two floors. The separation distance 8 meters. It has been built 7 years ago.

21 - A house was built from cement and stones. It contain two floors. The separation distance is 5 meters. It has been built 15 years ago.

22 - A house was built from stones and cement, it contain two floors. It has been built 5 years ago.

23 - A house was built from cement. It contain of two floors, it has been built 20 years ago. The separation distance is 5 meters.

24 - A house was built from stones and cement. It contain of two floors. It has been built 60 years ago.

25 - A house was built from stones and cement. It consisting of two floors. It has been built 60 years ago.

26 - A house was built from stones and cement. It consisting of two floors . The separation distance about 2 meters. It has been built 25 years ago.

27 - A house was built from cement, consisting one floor. Separation distance is about 3 meters. It has been built 25 years ago.

28 - A house was built from stones and cement, consisting of two floors and has cracks in the walls. The separation distance is 4 meters. It has been built 60 years ago.

29 - This house was built from stones and cement, it consisting of two floors and has a good ventilation. The separation distances is 8 meters. It has been built since 2000 .

30 - A house was built from stones and cement, it consisting of two floors. It has a good ventilation. The separation distance is 7 meters. It has been built 8 years ago.

31 - A house was built from cement. It has a good ventilation. The separation distance is approximately 6 meters. It has built 5 years ago.

32 - A house was built from cement. It is consisting of a ground floor. It has been built since 2008 .

33 - A house was built from stones and cement. It consisting of two floors and has a good ventilation. The separation distance is approximately 10 meters. It has been built 10 years ago.

34 - A house was built from cement. It consists of ground floor. It has been built 5 years ago.

35 - A house was built from cement. It is consisting of one floor . It has been built since 1980. The separation distance is approximately 3 meters.