An –Najah National University
Faculty of Graduated Studies

INDOOR RADON CONCENTRATION MEASUREMENTS IN FOUR HOSPITALS AND TWO HEALTH CENTERS IN NABLUS CITY

A thesis Submitted by
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Submitted In Partial Fulfillment Of The Requirements For The Degree Of Master Of Science In Physics, Faculty Of Graduate Studies, At An –Najah National University At Nablus City, Palestine.

June, 2001

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1. Dr. Ghassan Saffarini (head)	.....
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To

My parents

My family

AL –Aqsa martyrs

Islamic nation

Acknowledgments

First of all great thanks to God who gave me the power to complete this dissertation, also I am too much grateful to my family who gave me assistance throughout the course of this work. My special thanks to my supervisor Dr. Ghassan Saffarini who gave me full help and advice at any time and also I would like to thank Dr. Musa EL-Hassan for his help. I am grateful to Dr. Fakhri EL-Hasan for his advice. Thanks are also due to the administrators of physics laboratories particularly Sabri Atanna and to chemistry and biology administrators for their assistance.

Contents

Abstract

Indoor radon concentration has been measured in four hospitals (AL –Watani, AL –Ethad, Rafedia, AL –Enjeli) and two health centers (Mustwasf AL –Tadamon, Mustwasf AL–Rahma) in Nablus City. Forty-six solid state nuclear track detectors (SSNTDs) and fourteen kodalpha detectors were distributed in various locations among the four hospitals and the two health centers. Four SSNTDs and one-kodalpha detectors were lost. The SSNTDs detectors were etched in 6.25N NaOH at 98 ± 2 C° for about one hour and read under an optical microscope with magnification 100. The kodalpha detectors were read by the manufacturer in France. Indoor radon concentrations were calculated by using two calibration factors (5.3 ±0.5) and (6.68± 0.02) and compared with the values obtained from the kodalpha detectors. The results that were calculated by our calibration factor (6.68± 0.2) present

high correlation with those obtained from kodalpha detectors. The single values of radon concentrations of the calibration factor (6.68 ± 0.02) are more comparable, than those calculated by using the calibration factor (5.3 ± 0.5), with those obtained from using the kodalpha detectors. According to the results obtained from the calibration factor (6.68 ± 0.02) radon concentration vary considerably from about 11 to 154 Bq m^{-3} in AL–Watani, 4 to 200 Bq m^{-3} in AL–Ethad, 6 to 287 Bq m^{-3} in Rafedia, 12 to 35 Bq m^{-3} in AL –Enjeli, 14 to 96 Bq m^{-3} in AL–Tadamon, and 32 to 54 Bq m^{-3} in AL–Rahma. The average radon concentration is found to be 61.21 Bq m^{-3} in AL –Watani, 33.28 Bq m^{-3} in AL –Ethad, 92.03 Bq m^{-3} in Rafedia 23.85 Bq m^{-3} in AL –Enjeli, 55.19 Bq m^{-3} in AL –Tadamon and 45.84 Bq m^{-3} in AL –Rahma. On the basis of these values, the average of lifetime risk of radon induced lung cancer are, respectively, 6.19×10^{-4}, 3.36×10^{-4}, 9.29×10^{-4}, 2.41×10^{-4}, 5.57×10^{-4} and 4.63×10^{-4}

in AL–Watani, AL–Ethad, Rafedia, AL–Enjeli, AL–Tadamon and AL–Rahma. In terms of dose equivalent these average radon concentrations correspond to the effective dose equivalent of 3.6, 1.66, 4.60, 1.19, 2.76 and 2.29 mSv / y, respectively. Except in AL–Enjeli these doses are higher than the global value of 1.3 mSv/y.

Radon concentration results indicate that in some rooms the values exceed the 150 Bq m^{-3} which need remedial action.

Chapter one

Introduction

1.1– General Background

Humans have always been exposed to various amounts of ionizing radiation. The contribution of natural sources (either from terrestrial or from cosmic sources) was estimated to be 75 % of the total exposure [1]. Radon itself contributes about 52 % of the total exposure [2]. The amount of exposure depends on the specific characteristics of the region such as the geological and geographical factors and the radioactive material content in the region. After the pioneer discovery of x-rays it was known that ionizing radiation could cause many serious health hazards to the biological systems. Radon, being the most important source of ionizing radiation, can cause much more harm than other sources. The inhalation of short

lived radon daughters increases the probability of induction of lung cancer [3]. Consequently, the radon problem became a public concern around the world and many studies have been performed around the world on all aspects of radon gas radiation.

A study in the United Kingdom, where eighty-seven dwellings were measured, revealed that the mean radon concentration was 12.95 Bq m^{-3} [4]. In USA, measurements in central Florida show that radon daughters concentration within homes range from 3.7 to 370 Bq m^{-3} [5]. Also, a study of 26 dwellings in New York and New Jersey over a 2 – year period indicate a range of mean radon daughter concentrations from 7.4 to 37 Bq m^{-3} [6]. Further studies were performed in Jordan where CR-39 detectors were used to measure radon levels in Jordanian cities during the autumn. The average radon concentration ranged from 29.3 to 99.7 Bq/m^3 [7]. Recently, in Palestine, CR-39 detectors were used

to study the indoor radon concentrations in the buildings of Hebron University. The average radon concentration obtained in this study range from 20.5 to 41.3 Bq/m^3 [8].

Due to the scarcity of studies on the radon problem in Palestine, it was, therefore, interesting to conduct such a study in Nablus City.

1.2– Study Objective

The purpose of this study is to measure indoor radon concentrations in four hospitals (Rafedia, AL –Watani, AL –Ethad, AL–Enjeli) and two health centers (Mustwasf AL –Rahma and Mustwsaf AL –Tadamon). Passive detectors, CR–39 and kodalpha sensitive films were used in this study. Work has been carried out over a period of about 4 months.

In the next chapter the phenomena of radioactivity, types of decaying, radioactive law, half – life, natural ionizing radiation sources, types of ionizing radiation, ionizing

radiation interaction with matter, quantities and units frequently used in radiation protection, health effects of ionizing radiation and radiation protection system are presented. In chapter three, we present definition, origin, risk, and measurement techniques of radon gas. Chapter four gives the details of the experimental procedures and in the last chapter results are discussed and conclusions are made.

Chapter two

Radioactivity and Natural Radiation Background

2.1– Radioactivity

The phenomenon of radioactivity is naturally occurring in unstable nuclides as was discovered by Henry Bequerel in 1896. He noticed that, only uranium salts (from several materials, which were tested) caused the blackening of a photographic plate wrapped in light- proof paper. Soon after, Bequerel realized that the emitted radiation is not associated with luminescence and does not depend on external effect. Mari and Pierre Curie followed Bequerel work and from tons of uranium ore succeeded in isolating small quantities of two substances (polonium, radium) far more active than uranium. Curie's work led the way to the isolation and identification of

a large number of naturally radioactive nuclides. The emitted radiation from unstable nuclei was found to be one of three types alpha (α), beta (β) and gamma (γ) rays. The investigation of these types of radiation led to the conclusion that, nuclei have energy levels analogous to the atomic levels, and unstable nuclei decay in order to achieve a new configuration that is either stable itself or will lead to one that is stable. The phenomenon of radioactivity has assumed great importance in daily life, with potential for both constructive and destructive uses [9-11].

2.2– Nuclear Stability

Nuclear stability is controlled by two active forces [9,10,13], namely: -

1-Nuclear Force – it is very active over the short distance range between nucleons.

2-Electric Force – upon unlimited range (long range force) between charged particles (protons).

Light ($Z<20$) and medium ($20<Z<80$) nuclei, nuclear force dominates the electric force because the neutrons number (N) is equal to the protons number (Z) in light nuclei and larger than protons number (Z) in medium nuclei. So these nuclides are stable. While for heavy nuclei ($Z>82$) the electric force is far greater than nuclear force because of the large number of protons. So, these nuclides are unstable. Generally, nuclei that whose atomic mass number is greater than 209 ($A>209$) are unstable [9-14]. The above discussion can be summarized in fig 2.1, which is proton–neutron diagram for stable nuclide [12].

2.3–Types of Decay

Unstable nuclei may decay by one of three types (α, β,

and γ decay). We will discuss each one briefly, because the detailed discussion is beyond the scope of this research.

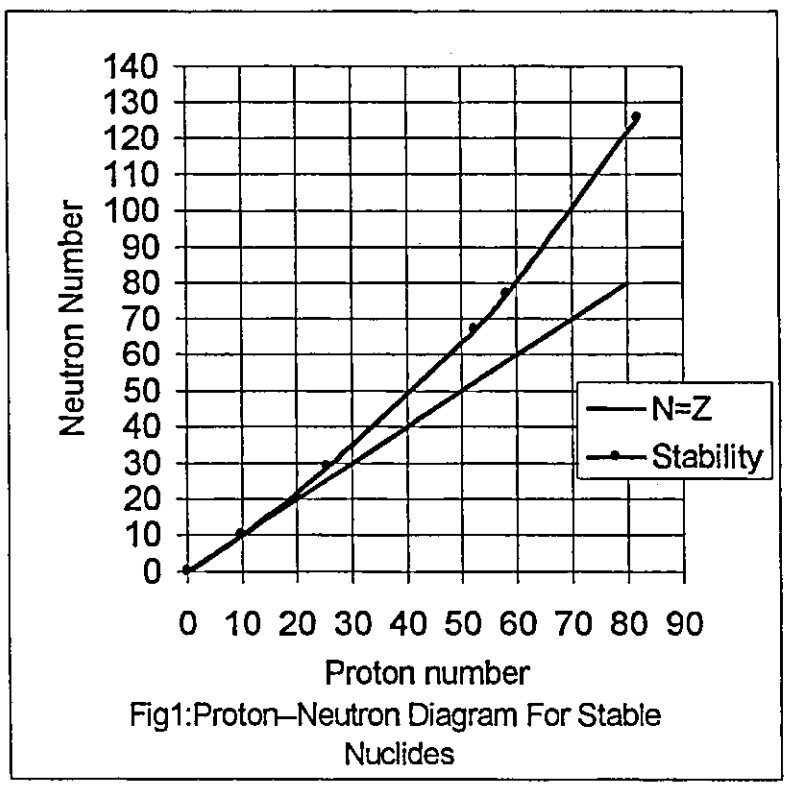

Fig1:Proton–Neutron Diagram For Stable Nuclides

2.3.1– α – decay

This process occurs in heavy nuclei that contain ≥210 nucleons, because the repulsive electric force between

protons dominates the nuclear force that hold the nucleons together, it makes these nuclei unstable. These nuclides achieve stability by emitting two protons and two neutrons as an entity particle (α particle), which is the nucleus of helium atom [9-11]. This process is accomplished in two stages: first, an α particle is formed as an entity particle within the nucleus and, second, the α particle is tunneled through a potential barrier. In this process mass, charge, energy and momentum are conserved [10-12]. The process is represented by:

$$^{A}_{Z}X_{N} \rightarrow ^{A-4}_{z-2}Y_{N-2} + \alpha$$

where X and Y represent the chemical symbols of the initial and final nuclei, respectively. An example of α-decay process is

$$^{226}_{88}Ra_{138} \rightarrow ^{222}_{86}Rn_{136} + \alpha$$

In this process the half-life is 1600 years and the particle appears with a kinetic energy of about 4.8 Mev [9].

2.3.2– β – decay

In this process a nucleus can correct a proton or neutron excess by directly converting a proton into a neutron or a neutron into a proton. This process can be achieved by one of three possible mechanisms: negative β decay (negatron), positive β decay (positron), and electron capture [9,10].

2.3.2.1– Negatron Decay (β^-)

In this process one neutron is transformed to a proton, an electron and an antineutrino* [9]. β^- decay occurs among neutron- rich nuclides. This process is represented by: -

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^- + \bar{\nu}$$

An example of this process is

$$^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + \beta^- + \bar{\nu} \qquad t_{1/2} = 29.1y$$

2.3.2.2– Positron decay (β^+)

In this process a nuclear proton is converted to neutron, positron** and a neutrino. Positron decay occurs among proton – rich nuclides [9,10]. This process is represented by:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \beta^+ + \nu$$

an example of this process is

$$^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + \beta^+ + \nu \qquad t_{1/2} = 2.605\ y$$

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*Neutrino: - a particle proposed by Palui to resolve the dilemma of the missing energy in beta decay process. The conservation of charge and mass required that, neutrino has no charge and its mass at most would be a small fraction of the electron mass. Neutrino speed is comparable to light speed and interacts with matter by week interaction .So , it has a large penetration ability of the matter [15].

**Positron:- is an elementary particle, identical to the electron except in that, electron charge is negative while positron charge is positive[9].

2.3.2.3– Electron Capture

In this process the nucleus absorbs one of the inner orbital electrons to convert a proton into a neutron and a neutrino [9-15]. This conversion is represented by

$$^{1}_{1}p + e^{-} \rightarrow ^{1}_{0}n + \nu$$

Electron capture is competitive with positron emission, since both processes lead to the same nuclear transformation. But, the electron capture occurs more often than positron emission in heavy nuclei. In contrast to alpha decay, the beta particle never exists within the nucleus as an entity particle, but is formed during the decay process from the decaying energy.

2.3.3– Gamma Decay

In this process, a nucleus in the excited state returns to its ground state by emitting photons traditionally called gamma ray. As a first approximation, the energy of the

emitted radiation is equal to the difference between the initial and final states in the transition involved. The emitted rays range in energy to several Mevs. An alternative process to gamma decay is called internal conversion, where the nucleus gives its excited energy to one of the orbital electrons. Gamma decay may occur as a separate process or a consequence of alpha or beta decay [9,10,15].

2.4- Decay Law

If N radioactive nuclei are present at time (t) then the number decaying in a time dt is proportional to N, that is

$$-dN/dt = \lambda N \qquad (1)$$

where the minus sign indicates the decrease in the number of nuclei [9,10,13,15] and λ is the disintegration constant, which does not depend on physical or chemical features of the sample. After rearranging equation (1) and carrying out the integration, one gets the following equation

$$N = N_0 e^{-\lambda t} \qquad (2)$$

where N_0 is the original number of nuclei at (t_0), and N is the number of nuclei at any subsequent time (t).

2.5– Activity

Because the decay process is statistical, it is difficult to count the remaining number of nuclei directly [9,10]. So, it is better to express the above formula in the form:

$$A_0 = A_0 e^{-\lambda t}$$

where A is the activity, defined as the number of nuclei disintegrating per unit time, and A_o is the initial activity at (t_o).

2.6– Half – Life

Half – Life is defined, as the time needed for half of the radioactive nuclei to decay and is given by the formula

$$T_{1/2} = 0.693/\lambda$$

2.7– Radioactive Equilibrium

Suppose we have a parent radioactive nucleus (A) that decays into the daughter radioactive nucleus (B) which in turn decays to a stable granddaughter nucleus (C). Then, the decay rate of A is [9,10,13].

$$dN_A/dt = -\lambda_A N_A$$

the net increasing rate in the formation of (B) is given by

$$dN_B/dt = \lambda_A N_A - \lambda_B N_B$$

and in the equilibrium state $dN_B/dt = 0$ then

$$\lambda_A N_A - \lambda_B N_B = 0$$

$$\lambda_A N_A = \lambda_B N_B$$

2.8– Natural Decay Series

There are three decay chains in nature: uranium (U^{238}), thorium (Th^{232}) and actinium (U^{235}) [9 –15]. Also, these series can be expressed in terms of the mass number as (4n+2), (4n), (4n+3), respectively, where n is an integer [15,17]. U^{238},

Th^{232},U^{235} are starting products of decay series whose members contribute to natural radiation . The more relevant among them are ^{226}Ra and especially ^{222}Rn [16]. The decay schemes of uranium, thorium and actinium are depicted in figure, 2.2, 2.3 and 2.4, respectively [17].

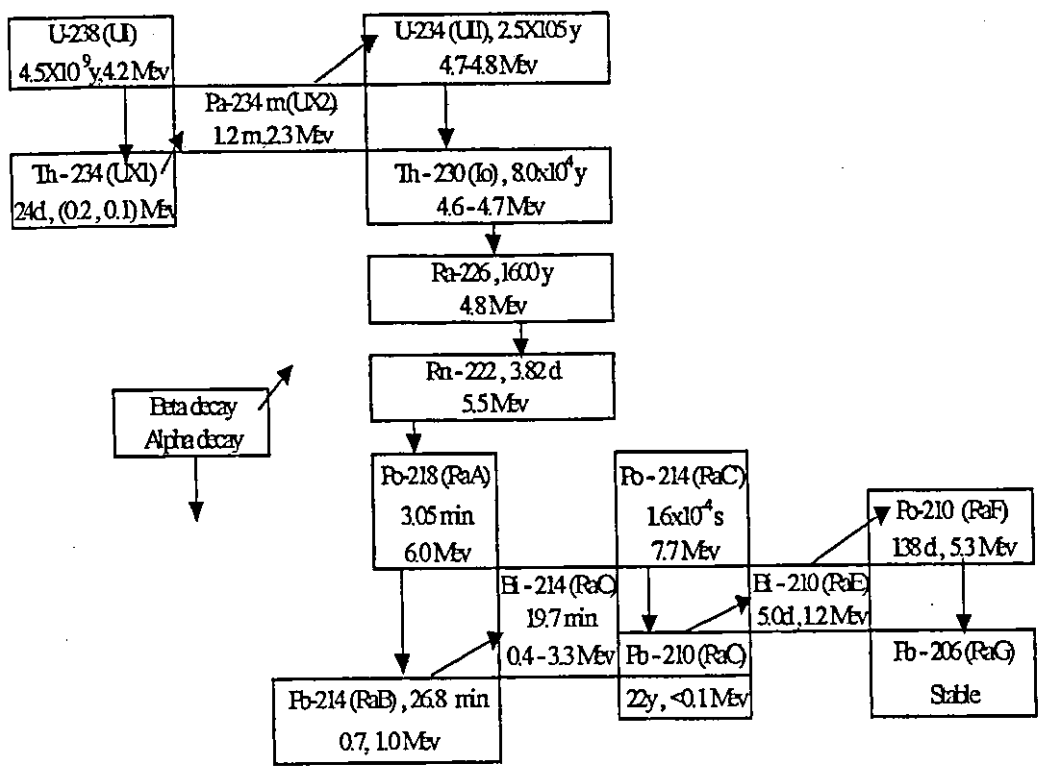


Figure 2.2: Principal decay scheme of the uranium series

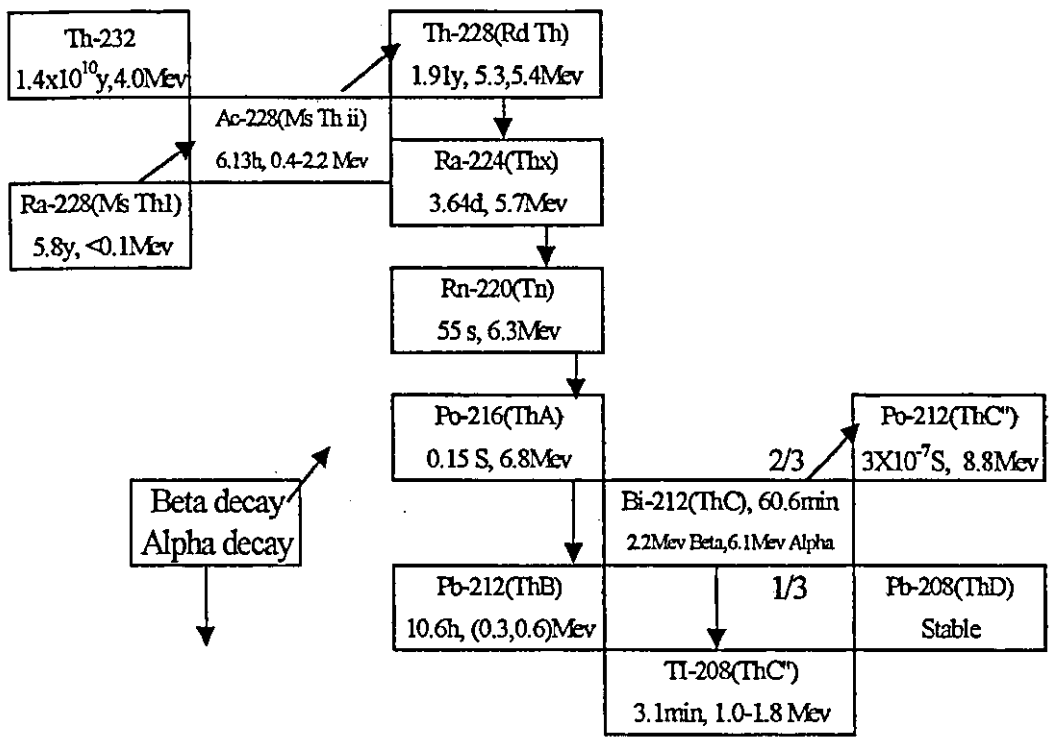


Figure 2.3: Principal decay scheme of the thorium series

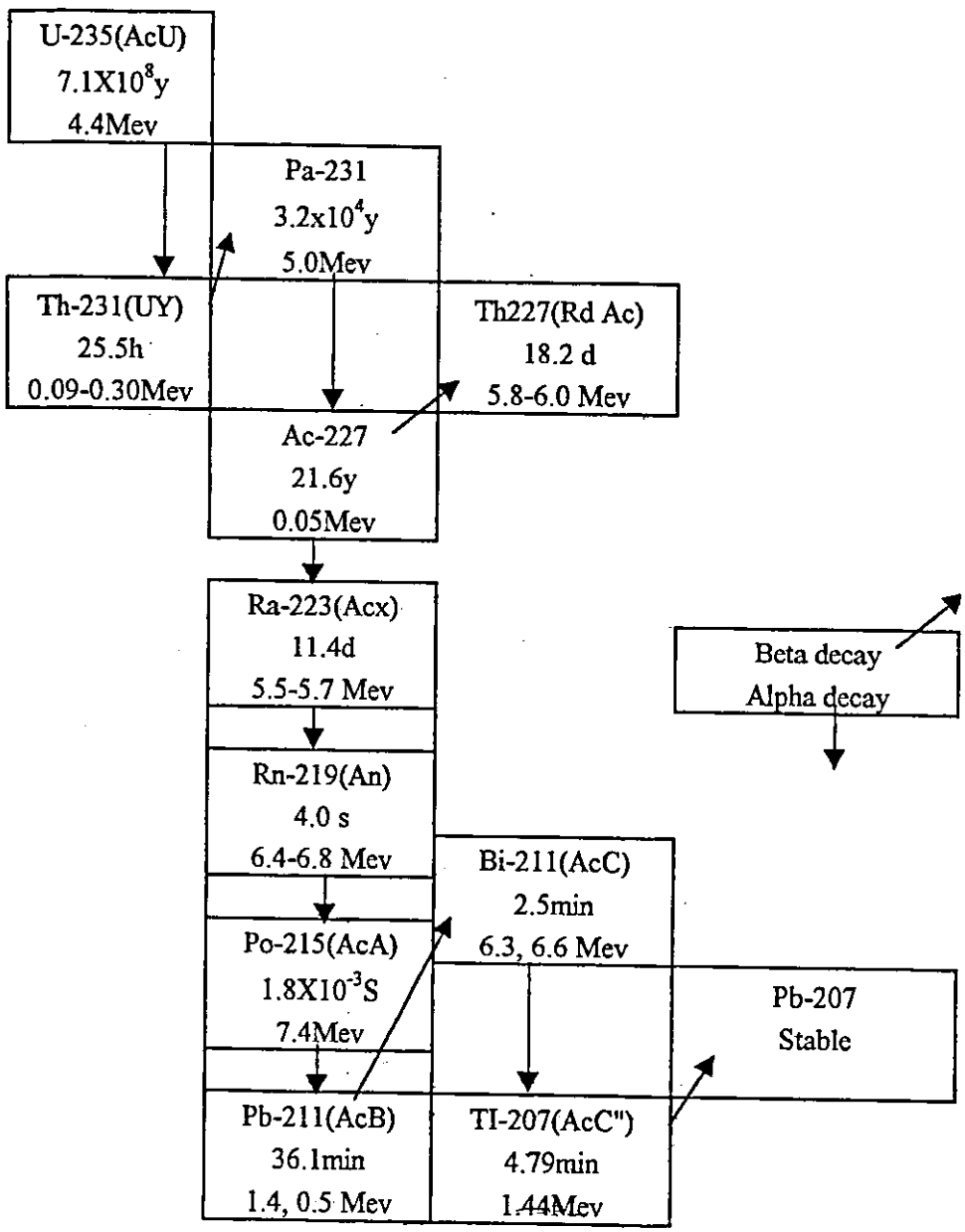


Figure 2.4: Principal decay scheme of the actinium series

2.9– Natural Ionizing Radiation

Natural ionizing radiation originates either from outer space (cosmic sources) or from terrestrial sources [16]. In passing through a medium they cause ionization or excitation to the medium atoms or molecules along their path in that medium. Direct ionization are caused by alpha and beta radiation while γ rays results in indirect ionization to the medium atoms. Due to the damaging action of ionizing radiation to biological systems they are considered the most important among other types of radiation (see table 2.1) [16].

2.10– Ionizing Radiation Interaction with Matter

An understanding of the ways radiation interacts with matter is a pre requisite for a good understanding of the effects of radiation on living systems. Interaction mode characteristics of different types of ionizing radiation will

affect the severity of physiological damage during exposure of living systems to ionizing radiation [9,10,13-23]. The biological activity of different kinds of ionizing radiation depends on the spatial pattern of energy deposition. A macroscopic parameter is used to describe it is the linear energy transfer (LET), which is defined as the energy deposited locally per path length [9,10,13-16]. Here, however, we confined our discussion with radiation emitted from natural radioactive materials that include: α, β and γ radiation.

2.10.1– α – particles

Alpha particles interact with matter via the two modes of interaction, ionization and excitation processes of the medium atoms or molecules [9-16]. If the energy of α-particle is equal or greater than the ionization energy of the absorber they interact through ionization, otherwise excitation will be

significant. In passing through a medium the alpha particle loses its energy by successive collisions with outer electrons of the atoms and create ion pairs along its path in that medium. These ion pairs also form incident particles, which in turn produce secondary ion pairs. The energy required to create an ion pair is 35eV (35eV/ion pair) [9,13,14]. Since the alpha particle is a heavy charged particle, its velocity, as we expect, in the material medium will be low. This means that the α- particle has greater interaction time near the medium atoms, which enhances the collision probability and energy deposition to these atoms. Therefore, the ionization density along α-particle path is so high and reaches the peak value at the end of the path where the α-particle velocity is smallest. The number of ionization processes depends on LET, which is very high for α–particles. It is to be noted that LET applies to the charged component only, because they are exclusively

responsible for energy deposition, and is usually measured in Kev/μm [13-16,18-23].

Table2.1:Estimated per capita annual effective dose equivalent from natural sources in areas of normal background [UNSCEAR (1988)] .

Source	Annual effective dose equivalent (Sv) External radiation	Internal radiation	Total dose
	Cosmic rays		
Ionizing component	300		300
Neutron component	55		55
Cosmogenic radionuclides		15	15
	primordial radionuclides		
^{40}K	150	180	330
^{87}Rb		6	6
^{238}U series			
^{238}U-^{234}U		5	
^{230}Th		7	
^{226}Ra	100	7	1300
^{222}Rn - ^{214}Po		1100	
^{210}Pb - ^{210}Po		120	
^{232}Th series			
^{232}Th		3	
^{228}Ra - ^{224}Ra	160	13	340
^{220}Rn - ^{208}Tl		160	
Total (rounded)	800	1600	2400

2.10.2– Beta Particles

Beta radiation consists of two types: negative beta radiation (e^-) and positive beta radiation (e^+) [9-15].

2.10.2.1– Negative Beta Radiation (electrons)

Electrons play an essential role in the ultimate deposition of energy with all kinds of ionizing radiation because they are always formed in the ionization process. Electrons interact with matter by one of three types: collisions with shell electrons, bremesstrahlung production, and emission of cherenkov radiation [15,16]. In terms of energy deposition collisions with shell electrons is the most relevant. Bremesstrahlung production becomes important at high energies while cherenkove radiation is generated if the speed of a charged particle passing through a medium exceeds that of light in the medium. Electrons, however, traveled with higher velocity than α- particles and with relatively long and

zigzag paths. The specific ionization of β particle is lower than that of α- particle, due to velocities and resulting reduced time near the medium atoms. The specific ionization of β-particle is greatest near the end of the path when kinetic energy has been significantly reduced. The penetration power of beta particles is higher than of alpha particle while LET due to beta particle is lower than that due to alpha particle [9-16].

2.10.2.2– Positron

Positrons interact with matter via ionization and excitation processes of the medium atoms or molecules. Positrons lose their energy through the medium by successive collisions with outer shell electrons of the medium atoms [9-15]. However, after positron energy is reduced to values comparable to that of surrounding extra nuclear electrons of the medium atoms, they will interact with negative electrons

and the masses of the two interacting particles will be converted to energy. Usually, this energy is emitted in the forms of two (0.511Mev) photons at 180° to each other. This process is called positron annihilation, which is the inverse process to the pair production.

2.10.3– Gamma Rays

Gamma rays, a form of electromagnetic radiation like light and x-rays interact with matter by one of three interaction types: photoelectric effect, Compton effect and pair production [9-15]. But the most relevant one is photo – electric effect. The high energy and the absence of charge and rest mass of the gamma rays means that it has a high penetration power, higher than α and β particles. Thus gamma rays produce less ionization than do alpha and beta radiation. Generally, most of the ionization processes result in the medium in response to secondary particles that are produced

by primary gamma rays. Finally, LET of gamma rays is much lower than that of alpha and beta rays.

2.11– Quantities and Units Frequently Used in Radiation Studies

Several quantities have been introduced in radiation studies to simplify the understanding, nature, and biological effects of ionizing radiation. Here, however, we introduce the most common quantities and units frequently used in radiation protection.

2.11.1- Quantities

1-Exposure (E):- A quantity defined as the total charge (of one sign) per unit mass liberated by ionization, measured in Roentgen, R , (R= C/Kg) E= dQ/dm [9,15, 16,21].

2-Dose (D): - Quantity of absorbed ionizing radiation, defined as energy absorbed per unit mass, D = dE / dm (j/Kg) [9,21].

3-Linear Energy Transfer (LET): - It is the amount of energy deposited per unit length, which is also a measurement of ionizing ability of radiation. Radiation of high LET has more damaging action to the biological systems than radiation of lower LET [15, 16,19]. The LET for alpha rays is higher than LET for beta rays which in turn is higher than gamma rays.

4-Quality factor (Q): - Q is a dimensionless factor defined as the weighting factor to account for the relative biological effectiveness of different kinds of ionizing radiation. It is used in radiation protection to determine the dose equivalent. Each type of radiation has a specific quality factor. Radiation of high quality factor is more hazardous than that of low

quality factor. Typical values are shown in table (2.2) [9,16,21]:

Table2.2: Q Values of Some Common Radiation

Radiation	Q
X and γ rays	1
β rays	1
Neutron, thermal	5
Neutron, fast	10
Protons	10
α-rays	20

5-Relative Biological Effectiveness (RBE):-A factor defined as the ratio of doses to give the same effect for different kinds of ionizing radiation compared to X or γ rays,

RBE = D(reference radiation) / D (test radiation) [9,16]

6-Dose equivalent (H):- H is defined as the absorbed dose (D) multiplied by the quality factor. [9,16, 21].

7-Weighting factor (W_T): - A factor representing the proportionate stochastic risk of tissue when the whole body is irradiated uniformly and the H_T is the mean dose equivalent received by the tissue T [21]. The values of W_T are recommended by International Commission on Radiological Protection (ICRP) and adopted by the National Council on Radiation Protection and Measurements (NCRP) for purposes of the recommendations on limit of exposure to ionizing radiation.

8-Whole body dose equivalent (Hwb): - Hwb is defined as the absorbed dose associated with uniform irradiation of the whole body [21].

9-Effective Dose Equivalent (H_E):- H_E is the sum over specified tissues of the product of the dose equivalent in tissue (T) and the weighting factor for t- hat tissue, $H_E=\sum W_T H_T = Hwb$ [21] .

10-Annual effective dose equivalent ($H_{E,L}$):- $H_{E,L}$ is the effective dose equivalent received by the body over a year [21].

11-stochastic effect: - effects, the probability of which, rather than their severity, is a function of radiation dose without threshold. More generally, stochastic means random in nature. The relationship between smoking and lung cancer is an example of a stochastic effect [9,21].

12-Nonstochastic effect: - Effects for which severity of the effect in affected individuals varies with the dose and for which threshold usually exists. The relationship between the consumption of alcohol and individual exhibits is an example of nonstochastic effect [9,16,21].

2.11.2- Units

1-Curie (Ci):- Ci is an old unit of activity defined as the measured activity of one gram (1g) of ^{226}Ra, which has an

activity of approximately 3.7x 10^{10} disintegration per second [9,15,16].

2-Bequerel (Bq): - Bq is the SI unit of activity which is equal to one disintegration per second, 1Bq= 1dps, 1Ci= 3.7x10^{10} Bq [9,16].

3-Roentgen (R):- R is the old unit of radiation exposure[9,13,14,18]. Roentgen is now defined as exactly 2.58x10^{-4}C/Kg. The roentgen was originally defined as that quantity of x and γ radiation that would produce 1esu of electrical charge of either sign in 0.001293 g of dry air (1.00cm^3 volume at STP). This can be shown to be approximately equivalent to 1.61x10^{12} ion pair per gram of dry air or the release of about 84 ergs of energy per gram of dry air at STP.

4-rad:- rad is the old unit traditionally used to measure the radiation dose .One rad is defined as that dose of one type of

radiation that will deposit 0.01J of energy in one Kg of absorbing material, 1rad = 10^{-2} J/Kg.

5-Gray (Gy):- Gy is the SI unit for dose of ionizing radiation and is the amount of radiation that will deposit one joule of energy in one kilogram (Kg)of absorbed material , 1Gy = 1J/Kg = 100 rad [9,14,18,21].

6-rem:- is the old unit of dose equivalent (H). Traditionally used by health physics in discussing radiation effects [9].

Dose equivalent in rem = dose in rad ×Q.

7-Sievert (Sv): - is the SI unit of dose equivalent deposited in body tissue, averaged over the body. One sievert (1Sv) = 100 rem = 1 J / Kg. Dose equivalent in Sv = Dose in Gray x Q [9].

8-Working Level (WL):- WL is the traditional unit of potential alpha energy concentration (PAEC) and defined as any combination of short-lived radon daughters in one liter of

air that will result in the ultimate emission of 1.3×10^5 Mev (2×10^{-5} Joule m^{-3}) of potential alpha energy [21,22].

2.12- Biological Effects of Ionizing Radiation

It has become clear that all various types of ionizing radiation present several hazards on biological systems [9,13-23]. These hazards are attributed to the biological material damage caused by ionizing radiation as a consequence of the ionization process, which they cause in the chemical constituents of the organism [16]. Harmful effects of ionizing radiation may occur at different biological levels (e.g. cellular, molecular, organ, and whole body level). But, since the cell form the elementary structure unit of the organism and the human body contains about 10^{14} of these elementary units, most radiation actions on the organisms as a whole can be traced back to cellular effects. The radiation chemical

processes are considered to be responsible for a great part of biological damage at cellular level. The two most important molecules that are affected by exposure to ionizing radiation are water, which is the most abundant molecule, and secondly the deoxy ribonucleic acid (DNA) as the most important molecule. The biological importance of DNA results from the fact that DNA is the carrier of genetic information.

Biological systems contain about 80% water, so it must be considered as a primary target for interaction with radiation. The initial products of the interaction of radiation with water both inside and outside the cell are H and OH free radicals, which damage the cell by causing oxidation-reduction reaction [20]. The primary radicals interact with each other to form the molecular products; molecular hydrogen (H_2) and hydrogen peroxide (H_2O_2).

The probability of inter radicals reaction depends, of course, on the proximity of their initial formation and hence is increased in the tracks of high-LET radiation. The biological importance of radiation induced free radicals lies in the fact that they react readily with solutions in their vicinity and thus able to damage DNA or other critical bio molecules [9,13, 14,16,20]. The damaging action of free radicals to DNA is an indirect effect of radiation, while on the other hand, DNA can be directly damaged by exposure to ionizing radiation. Radiation–induced alterations in DNA may lead to loss of viability, induction of mutations and initiation of cancer. The genetic effects of radiation are likely to be due to predominantly the damage induced in the DNA molecular structure [16,18,23]. In general, however, radiation effects on the biological cell are destructive effects which lead to

loss of function and change in its structure, these involve [13,14 ,16,23] :-

1-Cell death

2-Division delay or in other cases division impairment (inhibition).

3-Long term changes, which are transmitted to the future generation.

The most important thing that should be noted here is that the biological effects of radiation depend on many factors, such as: -

(I) Physical and chemical properties

(II) Biological factors

The first factor includes the physical and chemical properties of radiation such as types, energy and the solubility of radiation source [18,20-23]. The chemical

constituents of the exposed material also influence the radiation effects. Thus several quantities like dose, dose rate, dose equivalent, relative biological effectiveness (RBE) and quality factor have been introduced to encounter the different extents of the biological effects of different radiations. For example the dose equivalents in millirem and in mSv of 10 mrad of gamma, alpha and thermal neutron irradiation are [9]:-

γ: 10 mrad x1= 10 mrem x (1mSv /100 mrem)= 0.1mSv

n: 10 mrad x5 = 50 mrem x(1mSv /100 mrem)= 0.5mSv

α: 10 mrad x20 = 200 mrem x (1mSv /100 mrem)= 2mSv

We noticed from the above example that alpha radiation would produce more harmful effects than gamma or neutron radiation, even though the dose in (mrads) of all three is the same. But for the same type of radiation the severity of

effects depends on the dose size and dose rate. Some studies suppose a linear relation between effect and dose size. The chemical constituents of the biological system also play an essential role in the dose-effect relationship, some chemical molecules (i.e.H_2O, DNA) are more sensitive than other components. The second factors, biological factors are sex, age, tissue type and the health state of the irradiated individual. Young children are much more susceptible to the harmful effects of radiation than older adults. Here, however, we cannot discuss in detail all such effects and related factors. All we can do, here, is outline the basic effects of radiation. Most studies on radiation effects have divided the biological effects of ionizing radiation into two main categories: -

(1) Somatic effects: these effects would appear or continue to appear in the exposed person.

(2) Genetic effects: these effects would appear in progeny or future generations of the individual irradiated.

2.13– Somatic Effects

Somatic effects result from the damaging action of ionizing radiation to somatic cells (non-reproductive cells). These effects increase in severity with increasing absorbed dose in affected individuals, owing to the increased number of damaged cells and tissues. The dependence of somatic effects on the size of the absorbed dose required that the existence of a threshold dose level below which no observable changes occurred and above which noticeable changes occur. There is a direct relationship between the dose size and the severity of the effects after the threshold level is reached. In general somatic effects are classified into two types, viz. early and late effects.

2.13.1- Early Effects

Early effects occur at large doses received over a short period of time. These effects are usually seen on the whole body rather than in only few cells. The most important early effects are skin changes, alteration in the blood, gastrointestinal problems (including nausea and vomiting, general malaise and fatigue), central nervous system changes, lens opacification, loss of hair, loss of weight and decrease in sperm production in the male. But in extreme cases and at high doses death occurs within few weeks, days or hours after exposure. Some studies discuss these effects under (non-stochastic) effects.

2.13.2- Late Effects

These effects take from months to years to appear and would be observed in the various forms of cancers, cataract, sterility and aging and shortening of life span. Late and

genetic effects, which will be discussed in the next section, are discussed in some other studies under stochastic effects.

2.14- Genetic Effects

Genetic effects may appear in the future generations of the people involved in the radiation exposure [9,14,18,20,21,23]. The occurrence of these effect results from the changes induced by ionizing radiation in germ cells (reproductive cells). These changes involve: alterations in the elementary units of heredity, which are localized within the chromosomes, or by the induction of chromosome aberration, consisting of changes in the structure or number of the chromosomes [14,16,18,20,21,23]. Therefore, gene mutations are produced. The most symptoms of genetic defects include sterility, poor health, color blindness, mongolism and other types of malformations. Genetic and somatic late effects almost occur at low doses and the severity of these effects

cannot be defined in a quantitative way and there is no threshold dose. Only the probability of their occurrence is a function of dose. Our knowledge about these effects come from studies on the Japanese survivors of the atomic bomb at Hiroshima and Nagasaki and from the surveys of the old patients treated by radiation.

2.15- Radiation Protection System

Procedures that must be taken to prevent or reduce the radiation exposure depend on the route of exposure, which is divided into two types: external exposure and internal exposure.

2.15.1- External Exposure

A set of procedures have been put to prevent or at least to reduce the exposure level to the dose limit recommended

by the international agencies working in the field of radiation protection, these include [13,14,18]:

1-Exposure to radiation is prevented unless that is necessary.

2-Reducing the working time. The relation between the total dose and working time is: Total dose = dose rate × working time.

3-Increasing the working distance.

4-Using the radiation shields, the size of shielding depends on the type and energy of the radiation.

2.15.2- Internal Exposure

Internal exposure is much more hazardous than external radiation, especially with sources of long effective half-life (t_{eff}). The effective half-life is defined as the sum of reciprocal of biological half-life (t_B) and physical half-life (t_P) [13,14,21]:

$$1/t_E = 1/t_B + 1/t_P$$

After radioactive sources are taken into the body they may be distributed uniformly within the whole body or in a specific organ (called the critical organ). So it is hard but not impossible to remove the sources shortly after their entrance into the body [13,14,18]. A common practice in the attempt to remove these substances before they become permanently incorporated into tissues of relatively long biological lifetimes, such as the bones, is to administer complexing agent such as EDTA. It forms very stable complexes with radioactive substances provide a mechanism for their removal from the body [20]. In order to prevent the internal exposure, eating and drinking in the radiation work place is prevented and the consumption of food and water from polluted places is also prevented.

According to the above discussion many international agencies like ICRP, NCRP, UNCEARP, BEIR, (see appendix

B for acronyms), have always attempted to adopt radiation protection systems. This is usually done by either providing general instructions of the exposure situations or by predicting the permissible values of the dose levels for various exposure situations and the risk coefficients associated with exposure to ionizing radiation. The maximum permissible dose levels of the whole body of the public members for frequent and infrequent exposure are 1 and 5 mSv, respectively [21]. The value of the maximum permissible dose level of the workers in the radiation field for normal operation is 50 mSv, and the risk coefficient for somatic and genetic effects are 1.25×10^{-4}/Sv (often rounded to 1.00×10^{-4}/Sv) and 40.00×10^{-4}/Sv, respectively. These figures don't form a sharp line between safe and unsafe state form upper limits, above which remedial actions are recommended. In any case it is preferred to follow the ICRP

recommendations for the radiation protection when dealing with radiation, these include [9, 21]:

1-No practice shall be adopted unless its introduction produces a positive net benefit.

2-The exposure should be kept, As Low As Reasonably Achievable (ALRA) principle, economic and social factors taken into account.

3-The dose equivalent to individuals shouldn't exceed those limits recommended by the commission.

Chapter Three

Radon Radiation Problem

3.1– Radon Definition

Radon is a natural radioactive gas, having the symbol Rn and three isotopes of respective atomic weights 222, 220,and 219. Because radon is a member of inert gas family, it couldn't participate in any chemical reaction. Consequently it is able to migrate from soils and rocks into atmosphere [17,24 –26,27].

3.2– Radon Isotopes Discovery

Owens and Rutherford noticed strong electrometer readings when they were measuring thorium salts. In 1899 the strange readings were found to be caused by the diffusion of radioactive substances from the thorium salt through the ionization chamber. In 1900 it was found that actinium gave

an active emanation. One year later, Dorn found that radium salts emitted a gas similar to that from thorium and actinium [17,28].

3.3– Dosimeteric Properties of Radon Isotopes

The three radon isotopes (Rn –222, Rn –220, and Rn – 219) are members of the of three primordial series uranium (U –238), thorium (Th –232), and actinium (U –235) respectively [8,17,25,22,28 –31]. Rn –219 is the least abundant radon isotopes. This is due to the limited abundance of its parent (U –235), the concentration of U –235 (1.5 Bq Kg^{-1}) by weight in rocks and soils is generally <1% of U –238 concentration [3,8,17,22,27–31]. This, coupled with the short half –life (4s), has generally precluded direct measurement of this isotope in the atmosphere. On the other hand uranium – 238 and thorium –232 have approximately equal abundance (33 and 34 Bq Kg^{-1}) and they occur naturally in soils and

rocks in terms of alpha activity. Although Rn –222 flux (17 mBq m^{-2} s^{-1}) from soil is 100 times less than that of Rn –220 (1.5 Bq m^{-2} s^{-1}), Rn –222 is considered to be about 20 times more important in terms of environmental radiation than Rn – 220. The reason of this is the relatively long half –life of Rn – 222 compared with that of Rn –220 (55 sec). The term radon will therefore be used here to denote Rn –222. The dosimeteric significance of Rn –222 lies in the short lives of its alpha emitting daughter products, ^{218}Po, ^{214}Po [17,25,27,32]. The properties of some members of the natural radioactive series and those of Rn –222 and its short –lived daughters product are summarized in tables 3.1and 3.2, respectively [17].

Table 3.1 – Properties of some members of the natural radioactive series

Series	Long lived parent					Noble gas member		
		Crustal Abundance						
		α-Particle						
Common Isotopes	Half –life (y)	ppm	Bq/Kg	pCi/g	Isotopes	Name	Half –life	energy
Uranium ^{238}U	$4.5x10^5$	2.7	33	0.89	^{222}Rn	Radon	3.82d	5.49 Mev
Thorium ^{232}Th	$14.1x10^9$	8.5	34	0.92	^{220}Rn	Thoron	55.6s	6.29 Mev
Actinium ^{235}U	$0.7x10^9$	0.02	1.5	0.04	^{219}Rn	Actinium	3.96s	6.82 Mev

Table 3.2 –Radiometric properties of ^{222}Rn and its short-lived daughter products

Radionuclide	Half-life	Decay Constant(h^{-1})	Approximate Number of Atoms Bequerel^{-1} (Bq)$^{-1}$	Picocurie^{-1} pCi^{-1}
Rn –222 (α)	3.82 days	0.00755	47600	18000
Po –218 (α)	3.05min	13.6	260	10
Pb –214(β)	26.8min	1.55	2300	85
Bi –214 (β)	19.7min	2.11	1700	63
Po –214 (α)	164 μs	$1.52x10^7$	$2.4x10^{-4}$	$8.7x10^{-6}$

3.4– Radon Escaping Power

The term escaping power is used to denote the amount of radon released into the atmosphere relative to the total amount of radon produced in the host rocks and soils. The release of radon from natural minerals has been known since 1920, but the dynamics by which radon can be transported through soils and rocks into the atmosphere still need further studies. Most of these studies have been divided into two categories: one focuses on the release process of radon from the mineral grains composing the soils and rocks into the pore space between the mineral grains, known as the emanation power [17,22,28,33]. The other one studies the transfer of radon across the interface between the solid phase (soils, rocks, building material, or other substances) and the atmosphere (a closed vessel laboratory, a building or the out door air), and known as exhalation rate or flux [17].

Therefore, the term escaping power is used here to couple the emanation power with exhalation rate. It is influenced by four main factors:

1- Soil type and characteristics (uranium and radium content, grain size, moisture content, porosity, permissibility, etc...);

2- Meteorological factors (barometric pressure change, temperature, wind speed, rainfall, etc...);

3- Hydrogeological factors (presence of water in the pore space, fractures and micro fractures in the rocks, etc...);

4- Geophysics and chemistry factors (seismic and tectonic activities, earthquakes, volcanoes, the degree of radon solubility in the fluids between the pore space).

Radon is formed by the radioactive decay of radium, ^{226}Ra, which itself is a member of the uranium decay series. So, it is likely that radon is most commonly generated in the sites of uranium and radium, and a direct relation is found between

the uranium and radium concentrations in the rocks and soils and high concentrations of radon [26–36]. Although uranium and subsequently radium occur in virtually all type of rocks and soils, their concentrations vary with specific site and geological material. Some types of rocks have higher average uranium content (2.7ppm) than others [33]. These include light–colored volcanic rocks, granites, dark shales, sedimentary rocks that contain phosphate, and metamorphic rocks derived from these rocks. However, materials with sizable concentration of radium would be expected to show elevated radon concentration in soil gas and ground water of such mineralized area. Thus, the high concentration of radon in soil gas increases the chances that a large a-mount of radon migrates into the atmosphere.

It has also been found that the direction of the recoiling radon atom influences the release process of radon into the atmosphere. The range of the newly recoiling radon atom in

minerals of common density is from 20 to 70 nm [17,22,25,33]. If the direction of the newly recoiling radon atom points toward the surface, it may increase the amount of radon transfer into the pore space. On the other hand, if the direction of the newly recoiling radon atom is toward the core of the mineral it will be trapped in the rock and soil. In addition to the direction of the recoiling radon atom, location of the radium atom determines whether the newly recoiling radon atom will escape into the pore space or not. In solid materials gas diffuses slowly and only that radon produced near the surface of a solid, less than the range of the recoiling radon atom, will escape.

Positive correlation is noticed between the permeability of the soils and the radon release into the atmosphere. Radon moves more rapidly through permeable soils such as coarse sand and gravel, than through impermeable soils, such as clays [22,28,33,36,37,39]. Radon release is also influenced by

the grain size of the soils and rocks. It may be trapped in the rocks and soils of big grain size and doesn't enter the pore spaces between the mineral grains. In general, radon release is inversely proportional to the grain size.

A direct relation is observed between the porosity of the soils and rocks and the amount of radon release into the atmosphere [17,22,25,35,36]. After the radon is formed, it enters the pore spaces between the mineral grains and diffuses through soil–atmosphere interface. In the case of porous material sufficient amount of radon would be expected to escape into the atmosphere. An inverse relation is also found between the moisture content and the amount of radon spread into the atmosphere [17,2225,33,36,39]. The presence of water in the top layer of soil reduces the porosity of the soil. Thus, radon accumulates under this layer and dissolve in the water. Moisture content plays a less role in the case of permeable soil.

Positive or negative correlation has been observed between the escaping power of radon and the meteorological parameters [17,22,25,33,36,39]. An increase in surface temperature not only causes the soil gas to expand and escape but also tends to release the vapor species adsorbed to the surface of soil particles. Direct relation is also noticed between the wind speed and radon emission. The increase of wind velocity accelerates the flow of soil –gas. Negative correlation has been observed between the radon emission and the pressure change. Barometric pressure gradient may exert a pumping effect on the soil –gas. An increase in the atmospheric pressure tends to push the radon poor atmospheric air into the ground resulting in the fall of radon concentration, while the decrease in pressure lets the radon rich soil –gas escape from the deeper layer of the ground. A correlation has also been found between the rainfall and the

amount of radon escape into the atmosphere. Heavy rainfall dilutes the soil –gas and subsequently the concentration of radon decreases in the soil and increases in the ground water. On the other hand, light water doesn't percolate into the deeper layers and stay in the top layer causing the porosity to decrease. Therefore, radon accumulates with sufficient amount under this layer and in the case of increase of temperature and wind speed, a large amount of radon is released to the atmosphere. The presence of water in the pores of the mineral increases the radon emanating power [17,22,25,33]. A water film around mineral grains or other soil constituents slows down the radon produced having a considerable recoil energy thus avoiding implantation into adjacent grains. The accumulation of radon in the pore space increases the emission of radon into the atmosphere, as the water level drops.

Radon gas dissolve in the fluids between the mineral grains and the degree of solubility depend on the nature of the solvents [22,25,25,33]. So, radon gas can be found at some distance from the location where it was initially formed. The ease and efficiency of movement of radon –bearing fluids in rocks and soils determine the amount of radon release into the atmosphere. Also, anomalous radon level is found to be correlated with seismic and tectonic activities. During volcanic eruption many materials of high uranium and radium content are pushed up to the surface which in turn increase the released of radon into the atmosphere [22,26,37,40 –42].

3.5– Indoor and Outdoor Radon Concentration Levels

It is well known that high concentration level of radon can be found almost in closed places and poor ventilated buildings such as caves, dwellings, and mines [8,17,22,25,31,43–47]. Radon radiation has always been part

of the human environment and generally the emission source can't be regulated, it is considered a unique pollutant. Indoor radon concentration level can build up to dangerously high levels, several times higher than that of the outdoor, in building of poor ventilating conditions. Outdoor radon concentration doesn't constitute a serious problem in the free atmosphere because it readily disperses and decays. Indoor radon concentration and consequently exposure, are influenced by many factors, such as:

1-Escaping power of radon

Soils beneath and around the houses are the main sources of the indoor radon concentration [22,25,26,28,30,32,42–46]. In homes that have been built on soils of high escaping power, elevated indoor radon concentration would be expected (see the previous section).

2- Ventilation Rate

Under conditions of low air exchange rate, radon could accumulate to a very high level within one day [8,17,22,25,46–48]. Indoor radon concentration level can be reduced to low levels by increasing the ventilation rate. Low ventilation rate and high outdoor radon concentration led to elevate indoor radon concentrations. On the other hand, the strong mixing of outdoor with indoor air makes the indoor radon concentration level very close to the outdoor radon concentration level.

3 –Meteorological Condition

Meteorological conditions also affect the indoor radon concentration. Radon moves in the atmosphere by diffusion and/or convection [22,25,28,31,32,39,41,46]. In wet climate radon moves very slowly than in dry air. Thus radon can accumulate to high levels, and elevated indoor radon concentrations can be reached in poor and tight buildings. Also in areas with high wind speed, radon readily disperse in

the atmosphere which in turn reduces the indoor radon concentration. The presence of high atmospheric pressure gradient across inside and outside buildings increases the air exchange rate thus reduces the indoor radon concentration. Thermal gradient also drives convection currents, and causes radon to disperse.

4 – Short –Term and Long –Term Variations

Short–term (day and night) variation of radon is significant and the maximum level of radon is found during the night and at early morning. On the other hand, minimum level of radon is observed during the day particularly in the afternoons. In ground floors, windows and doors are closed at night for heat saving and security reasons, and the atmosphere is usually very stable in the early morning due to the temperature inversion, causing radon concentration to rise. Radon concentration is also affected by long–term (seasonal variation), it is found that indoor radon level peaks in winter

and reach minimum level in summer in cold climate. In hot climate, however, the maximum level occurs in summer and the minimum level in winter [17,22,25,28,37,39,47.48].

5 –Building Materials type

Building materials contribute somewhat to the indoor radon concentration. This contribution is dependent on the source from which these materials were extracted [17,,22,25,27,31,47–50]. Radon can readily diffuses from building materials, in the same manner as it does from the soils and rocks, into the indoor atmosphere.

6 –Buildings Style

The size and number of spaces between the buildings in addition to the proximity of these buildings the ground influence the indoor radon concentration [22,25,32,45,47,50]. The increased number and size of windows and doors induce high air exchange rate that tends to reduce the indoor radon concentration to a significant level. If the floors and walls of

the house were close enough to the ground surface, high level of indoor radon would be expected. Indoor radon concentration level decreases with height, so basements have higher indoor radon concentration than upper floors [25]. In some cases, however, indoor radon concentration in upper floors is higher than in basements and ground floors. This can be explained by the chimney effect, which occurs whenever a vertical channel exists. Vertical channels bring up the air from the basement through pressure or temperature differentials. The chimney effect can serve as an entry route in a house built with hollow block basement walls, which can funnel soil gases up through the walls to the first floor.

7 –Family habits

The occupants' behavior is also responsible for variations of the indoor radon concentrations. Opening and closing of doors and windows, which is frequent in homes with many

occupants or with children, tends to decrease the indoor radon concentration [25,50,51].

8–Snow effect

The snow traps radon emanating at the soil interface on the outside of the foundation, thus allowing radon to diffuse into the basement. When the snow piles up against the house the indoor radon concentration level increases and removal of the snow lowers the levels.

9–Water Source

Water in earth is always close to the soil and rocks, so it is not strange that water contains radon [22,25,26,31,32,45,50]. Radon as a gas dissolves in water and can be released to the indoor atmosphere through the usage of water by occupants such as taking showers, washing clothes, and cleaning the dishes and so on. Water contribution to the indoor radon concentration level depends on the water source and the distance between the water source and the foundations. The

relatively short half–life (3.82d) and the long distance between the water source and homes may cause a decrease in radon concentration, to a significant level, through the decay process. Municipal treatment of water also causes a decrease in radon concentration. It is well known that well water has higher concentration of radon than the water from the public utility systems.

10– Burning of Natural Gas

This fuel contains varying amounts of radon, depending on the source and the time that the gas spends in transit and storage [22,25,31,50].

3.6 –Route of Radon Enters Homes

Radon can enter homes by the following pathways:

1- Natural diffusion from the building material [22,25,37,50,52].

2- Openings of the houses (windows and doors): radon is transferred from outside to inside by natural diffusion and convection current [25,39,42].

3- Cracks in basement walls, floors, and ceilings are the most common source of radon diffusion into the home. These cracks can be microscopic but still effective [25,32,53,54].

4- Joints between walls and floors [3,22,25,26].

5- Sumps without cover or with loose –fitting cover are the most common entrance pathways in the case of water – born radon [25].

6- Loose fitting pipe through walls or floors and floor drains connected to weeping tiles provide a direct pathway of radon into the basement [3,25].

3.7–Routes of Radon Exposure

1- Inhalation: inhalation of the short –lived radon daughter products is considered the most important route of radon

exposure. The short–lived daughters of radon can be easily attached to the ambient aerosols and dust particles, thus during the breathing process, these daughters enter into the lungs and deliver a considerable dose to the lungs.

2- Ingestion: radon can also enter the body through ingestion in drinking water that contains radon. Kidneys are the most common target of this route of radon exposure [22,25].

3- Internal exposure: human body contains an amount of radium and uranium and these radionuclides are thought to be residing in the skeleton [21,22,25]. The decay of radium produces radon and this radon may dissolve in the body fluids and is transferred through fluid rotation into other organs.

3.8– Radon Risk

One who is exposed to the radon radiation wouldn't instantly feel any effect. This comes from the fact that radon is colorless, odorless, and tasteless [8,54]. Its effects may appear after a long time in different symptoms like lung and other types of cancer [45]. According to the Harley and Pasternack's model a 5–year latent period, no lung cancer appearing before age 40 and a 20–year half–time for an apparent reduction in effect with time which may be attributable to cellular repair or to some other cause [25].

The epidemiological studies and assessment of lung cancer risks among miners supported the idea that high rates of lung cancer are caused by the exposure to high levels of radon. The connection between radon and lung cancer in miners has raised concern that radon in homes might be causing lung cancer in the general population [44]. However, the detrimental effects of radon exposure on the health of

general population are well known and appreciable correlation has already been established between radon exposure and lung and skin cancers besides kidney diseases [51]. In the USA and in many parts of the world, radon gas and its decay products may represent a major cause of lung cancer. It has been estimated that ~ 10% of all lung cancer deaths in the U.S.A. are directly attributable to radon exposure and its decay products. Also in the U.K., radon may be responsible for anything up to 2500 or more lung cancers in a year out of the total of 4100 [28,30].

The risk is not due to radon itself but rather due to the short–lived radon daughters. These daughters are electrically charged and solids and can attach themselves to tiny dust particles in indoor air and be breathed into the lung. Alpha particles from radon progeny particularly (^{218}Po, ^{214}Po) directly damage target lung to cause cancer [22,25,54]. They can also disrupt DNA of these lung cells. This DNA damage

has the potential to be one step in a chain of events that can lead to cancer. Because alpha particles from the decay of radon progenies in the lung travel only extremely short distances in the body, lungs are the most common target of these particles than other organs of the body [44,55]. In addition to the dose rate, the effect of radon exposure depends on the age, and that the risk of radon exposure is higher for children than that for adults [55–57].

There is a relation between radon health effects and smoking. Smoking has clearly been identified as a factor causing lung cancer risk and is a major confounded of the radon effect. Most of the radon –related lung cancer occur among ever smokers [3,44,56]. An estimated 8–25% of all current lung cancer deaths are thought to be due to past exposure to air born radon or to radon acting together with cigarette smoke [45].

3.9– Radon Measurement Techniques

Radon concentration measurements have now become very important, especially after the realization of the radon hazards to the population. In present dwellings indoor radon concentration measurements are very important in determining whether the concentration levels are in the range of accepted level or not. For future buildings the measurement of radon concentration in soil air is a useful tool in the planning and construction, in order to avoid high indoor radon levels [17,25,39,50]. In the last few years various measurement techniques of radon and its daughters have been developed and became available for use by a wide range of countries. There is no single technique that can meet all requirements of the different types of radon and its daughters measurements. The choice process by which one of these techniques are used depends on the purpose and type of the survey, and the cost of the apparatus, etc [22].

3.9.1– Radon Measurement Purposes

In general there are four purposes of radon measurements [17]:-

1- Evaluation of human exposure.

2- Identification of high radon areas.

3- Scientific studies to determine fundamental mechanisms.

4- Diagnostic measurements, for remedial action.

3.9.2– Types of Survey

With each one of the above purposes there is a particular type of survey [17,22]. For human exposure evaluation, long–term measurements or multi–spot measurements should be made. While short–term measurements and continuous measurements are suitable for screening geographic areas of high exposure and scientific

studies, respectively. Radon survey (sampling) processes are divided into three categories [17,22,25,42]: -

(1)-Instantaneous survey (known as grab sampling).

(2)-Continuous (real time) surveys.

(3)-Time averaged survey, used to determine average concentration in selected time intervals.

3.9.3– Radon Measurement Devices

Several devices have been developed for use in radon measurement. Survey type, instruments cost, and the simplicity of operation play an essential role in the selection process of the most appropriate instruments. Radon measurement devices have been divided into two types [22,58–60]: -

(1)-Active devices: power is required in the operation of these devices during the sampling process.

(2)-Passive devices: no power is required in the operation of these devices and the sampling process is achieved by natural diffusion of the radon gas into the container through thin membrane.

Passive devices (detectors) have been used extensively in radon measurements. Already these detectors include three types:-

1- Solid state nuclear track detectors (SSNDs).

2- Activated charcoal (charcoal canister).

3- Thermolummesence detectors.

4- Kodalpha detectors.

D.A.Young was first to discover SSNDs in 1958 [60]. He noticed that LiF crystals, held in contact with a uranium foil and irradiated with thermal neutrons, revealed a number of etch pits after treatment with a chemical reagent. It seemed that each pit was formed around the site of solid –damage produced by the fission fragments. Etched tracks have now been observed in a large number of materials. These materials

are general polymers, inorganic glass, mineral crystals, and some poor semiconductors. The most important generalization that can be made about these substances is that they are all dielectric solids i.e. poor conductors of electricity [60].

The durability, the simplicity and the markedly specific nature of the response of these detectors led to their rapid application in a wide variety of fields. But the initial application of the etched track radon dosimetry was at J.Stefan institute in 1976 [22]. Solid state nuclear track detectors (SSNDs) have become an important tool in the investigation of the presence of radon gas, not only in indoor air but also in soil [3,17,22,60]. At present the technique of a track –etch, for total indoor radon measurements, is widely applied in Europe. Nuclear track detectors can be deployed to determine time–averaged concentrations for long time intervals, up to one-year exposure are common. Nuclear track

detectors detect the alpha particle produced from the decay of radon and its daughters. It has more advantages and special characteristics over other techniques, which include:

1-Maintaining permanent records of tracks;

2-Can integrate radon over any length of time (from a few days to one year);

3-Little or no dependence on environmental conditions such as temperature and humidity;

4-Passive and integrated detectors;

5-Small in size;

6-Easy to construct and use;

7-Inexpensive;

8-Detect alpha but not gamma or beta radiations.

Etchable tracks are produced only by heavy ionizing particles. Heavy particles passing through insulating media leave narrow (~ 30 ~ 100 Å) trials of damage [60]. In crystals

this consists of atomic displacements, manifesting themselves as interstitial and vacancies and surrounded by a region of considerable lattice strains. In plastics, the radiation damage produces broken molecular chains, free radicals, etc. Track formation is related to the production of dense regions of ionization and the linear rate of energy loss (-dE/dx) in the stopping medium by charged particles. Track formation, to first approximation, can be regarded as occurring when the number of ions and (-dE/dx) exceed certain threshold values. These thresholds vary from one type of material to another. The type of damage produced by ionizing radiation depends not only on the nature of the ionizing radiation but also on the nature of the solid itself. Tracks can be observed in substances whose resistances are equal or greater than 2000 Ω cm. Early studies showed that these etchable tracks were:

1-Produced only by heavy ionizing particles (e.g. α–particles in the case of plastic, and fission fragments in the case of crystals);

2-Produced only in the electrical insulator or poor semiconductors;

3-Stable even when subjected to light or to high doses of x-rays, β– particles, ultraviolet radiation, etc.

Chemical etching is the most widely used method of fixing and enlarging the image of the latent damage trail in a solid state track detector. Certain chemical reagents (etchants) dissolve or degrade damaged regions at much higher rate than the undamaged regions in the material of solid state nuclear track detector. The most appropriate one is found to be NaOH. The narrow damage trail is thus gauged out by the etchant, forming a hole.

The etched track may be enlarged radially until it is visible under an optical microscope. The linear rate of chemical attack along the track is termed the track etching velocity V_t. The surrounding undamaged material is attacked at a rate V_B, the bulk etching velocity (see equation (3.1,3.2). Etching time will vary according to the exact etching conditions (temperature and concentration of etchant) and the nature of the track –forming particle [60].

The incidence of a charged particle on the surface of a detector may be vertical or inclined with angle (θ). A vertical track results in the case of vertical incidence and the etch–pit opening seems to be a circle with diameter d (see fig 3.1). The inclined incidence produces inclined track with angle (θ) to the surface and elliptical etch–pit opening with the major axes (D) and minor axes (d) [60].

$$d = 2VBt\sqrt{\frac{V_T - V_B}{V_T + V_B}} \qquad (3.1)$$

$$D = \frac{2\,VBt\sqrt{V^2{}_T - V_B{}^2}}{V_T\,Sin\theta + V_B} \qquad (3.2)$$

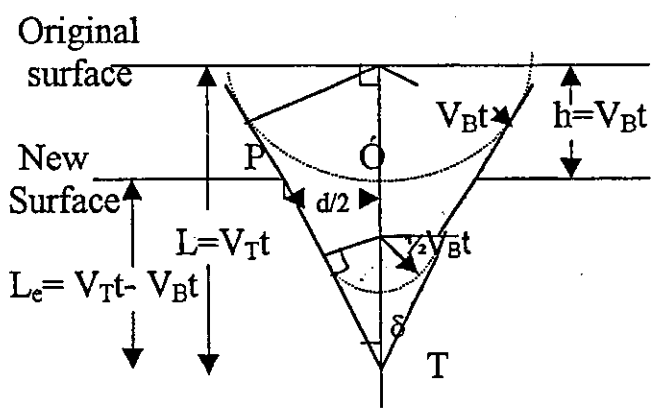


Figure 3.2: Geometry of etch –pit

where

V_T: track –etching velocity

V_B: bulk –etching velocity

t : duration of etching

d : diameter of etch –pit opening

L_e : length of etch –pit

δ: semi –cone angle

3.10– Action Level and Remedial Action

The permissible level of radon exposure recommended by the local or national authority is called the action level. When the indoor radon concentration level exceeds the action level, various procedures must be taken to mitigate (reduce) the indoor radon concentration to a level less than or equal to the action level. These procedures are called remedial action [22,25]. Because the exposure circumstances are not the same, the action level is different from one country to another. Each country has a especial actin level. For example the action level in UK, Sweden, China, and Australia is 200 Bq m^{-3}, in U.S.A it is 148 Bq m^{-3}, in Germany is 250 Bq m^{-3} and the action level set by the international commission on radiological protection (ICRP) ranges from 200 to 600 Bq m^{-3}

[22,30,34,4461]. There are no standard techniques for all situations of exposure. However, the following general procedures may be used to reduce the radon concentrations:-

1-Removing the source of radon.

2-Placing a barrier between the source and the open living space.

3-Diverting the radon before it enters the structure.

Installing air cleaning equipment.

4-Increasing the ventilation rate.

Many studies showed that ventilation rate play an essential role in reducing indoor radon levels [22,25,46,50]. All remedies have some cost, for example increasing home ventilation or removing contaminated material from or around houses require some expenditure and effort.

Chapter four

Experimental Work

4.1– Introduction

The experimental work of this study was performed through four main stages.

1- Dosimeters preparation and distribution;

2- Dosimeters collection and chemical etching;

3- Dosimeter calibration;

4- Microscopic scans of the detectors and calculation.

4.2– Dosimeters Preparation and Distribution

Two types of detectors, solid state nuclear track detectors (SSNTDs) of CR–39 type and kodalpha films, were used in this study. The CR–39 detectors is a plastic film of passive type manufactured at Bristol University under the name TASTRAK. TASTRAK was firstly derived at Berkeley

from CR–39, which stands for Colombia Resin. Several properties make the CR–39 detectors extensively used in radon measurements [17,22,37,60,62].

The CR–39 detector of dimension 1.5 cm × 1.5 cm was fixed in the bottom of plastic cup, by blu–tac. The cup was covered by a thin membrane to exclude the radon daughters and dust (see fig 4.1). So, diffuses radon only into the cup and disintegrates by emitting alpha particles. The particles hit the detector surface and leave latent tracks along the trials of alpha particles. The latent tracks of alpha particles were fixed and enlarged by the etching process.

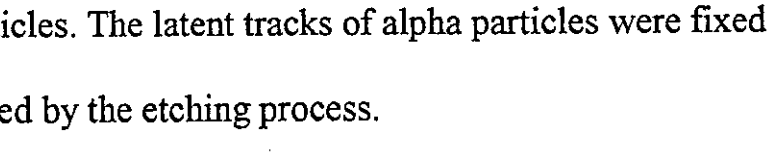


Figure 4.1–Radon dosimeter

Forty-six dosimeters were distributed, in February, in various places selected randomly among the four hospitals

and the two health centers in Nablus City (see table 4.1). The dosimeters were mounted on the walls of the measurement places at about 1 to 1.5 m from the ground. At the same time fourteen kodalpha films were also randomly distributed alongside the CR–39 dosimeters. The kodalpha films were located at the same places and height of the CR–39 dosimeters. Kodalpha is an alpha track detector (ATD) of passive type with open face. Kodalpha was developed by the CEA commission Board of atomic energy in France for kodak. For the following properties: -

1-Very sensitive to alpha particles only;

2-can be used for short term measurements at a minimum of 10 to 30 days of exposure, and also for long term measurements, three month up to one year;

3-insensitive to environmental changes such as humidity, water and temperatures up to 60 C^{o};

4-easy to use and maintaine everywhere;

5-suitable to use for radon measurements in stagnant or flowing water and in oil.

Kodalpha has been used for radon measurement by many laboratories throughout the world and by most important radiation safety institutes like the EPA and NRPB.

4.3– Dosimeters Collection and Chemical Etching

Thirty-eight dosimeters were collected in June 1999 and two dosimeters were collected in July 1999 because the employees were in holiday and the places were closed. Four CR–39 dosimeters were lost and the other two were collected in April for training purpose of the chemical etching process. On the other hand, thirteen kodalpha films were collected in April and sent to the manufacturer in France for reading. One kodalpha was lost (see table 4.1).

Chemical etching of the detectors was used to fix and enlarges the alpha tracks in the detectors to make them visible

Table 4.1: Detectors distribution and collection

Measurement place name	Distribution			Collection				Lost	
	Date	number of detectors		Date	Exposure time (months)	number of detectors		number of detectors	
		CR-39	Kodalpha			CR-39	Kodalpha	CR-39	Kodalpha
AL-Watani hospital	08/02/99	9	2	02/05/99	2.80	*2			
				15/04/99	2.23		1	3	1
				15/06/99	4.23	4			
AL-Ethad hospital	09/02/99	10	3	15/04/99	2.23		3		
				15/06/99	4.20	8			
				08/07/99	4.97	2			
Rafedia hospital	09/02/99	9	1	18/04/99	2.30		1		
				15/06/99	4.20	9			
AL-Ejeli hospital	03/02/99	5	2	18/04/99	2.50		2		
				16/06/99	4.43	5			
AL-Tadamon health center	02/02/99	8	5	18/04/99	2.53		5		
				15/06/99	4.43	8			
AL-Rahma health center	03/02/99	5	1	18/04/99	2.50		1	1	
				15/06/99	4.40	4			

* These two detectors were collected for training purpose of the chemical etching

under an optical microscope. All of the detectors were etched in sodium hydroxide (NaOH) solution of 6.25normality (N = 6.25) for one hour at a temperature of 98 ± 2 C° [62]. The following steps show the chemical etching process of the CR –39 detectors:

1-The instruments (hot plate with thermostat, heating dish, graduated cylinder, thermometer, sensitive balance) and materials (distilled water and sodium hydroxide (NaOH));

2-the hot plate was turned on and the temperature was adjusted to 100 C°;

3-the NaOH solution was prepared and placed on the hot plate;

4-the solution temperature was monitored by constantly viewing the thermometer. In order to get the correct temperature the thermometer must stand vertically and not be allowed to touch the dish bottom;

5-the CR–39 detectors were then put in the solution of 100 C^{o} and the started time was noted;

6-the solution was constantly stirred in order to a void the corrosive layer formation on the detector surface;

7-after one hour, the hot plate was turned off and the dish lifted up;

8-the detectors were then removed from the solution and extensively washed by tap and distilled water respectively, and dried.

4.4– Dosimeter Calibration

Radon dosimeter was calibrated in (0.5 m × 0.5 m × 0.5 m) cubic wood box by using a standard radon source, solid radium –226 (Ra–226), of activity 17420.90 Bq. The concentration of radon (Rn–222) in 1 m^3 is 21552.61Bq m^{-3}. The internal sides of the box were covered by aluminum foils. The source was left alone in the box for about one month to

create a suitable radiation environment. Then, the dosimeter was put in the box for a period of 48 hours with the source. The distance between the source and the membrane covering the dosimeter was kept at 3 cm (see fig 4.2). Finally, the detector was etched using the same procedures mentioned above and read by an optical microscope with a magnification of 100 (10 × 10). The calibration factor was found to be 0.149789-track cm^{-2} d^{-1} Bq^{-1}.

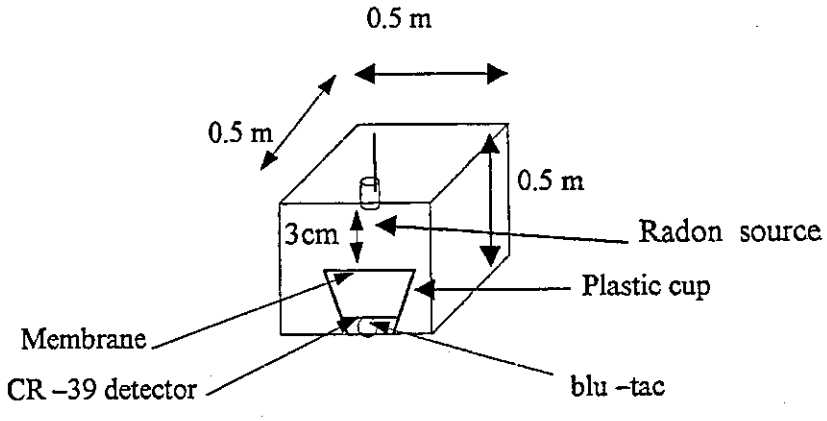


Figure 4.2: Radon source and radon dosimeter inside the calibration chamber.

4.5 –Detector Scan and Calculation

Each CR–39 detector was scanned randomly from ten to fifty fields of views. The area of the field of view was calculated by using stage slide and found to be 254×10^{-4} cm^2. For each detector the number of tracks was averaged over all fields of views. In the counting process of the tracks care must be taken to distinguish between the tracks and dust particles. Alpha tracks appear as black holes with different volumes and shapes. The track volume depends on the interaction energy between the alpha particle and, detector material and the etching process, so that track ranged from large to small size. The shape of the track depends on the angle of incidence of the alpha particle. Circle or ellipse faces of the track result from vertical and inclined incidence, respectively. The tracks were clarified by turning the coarse and fine focus dials. As long as the coarse and fine focus dials

are turned, tracks still appear and seem to be as small balls, while dust particles disappears (see fig 4.3).

The average number of the tracks was used to calculate the average number per cm^2. These values were then used to calculate the radon concentrations. The annual effective dose equivalent as well as the annual lifetime risk of radon induced lung cancer were also obtained from the values of the radon concentrations. In calculating the concentration we used two calibration factors. The first one is derived at Bristol University (equation 4.1) and the other one is derived at our laboratory at An–Najah National University (equation 4.2), these are:

$$\text{Activity in Bq m}^{-3}\text{ of radon in air} = \frac{(5.3 \pm 0.5) \times \text{track count cm}^{-2}}{\text{exposure in days}} \quad (4.1)$$

$$\text{Activity in Bq m}^{-3}\text{ of radon in air} = \frac{(6.68 \pm 0.02) \times \text{track count cm}^{-2}}{\text{exposure in days}} \quad (4.2)$$

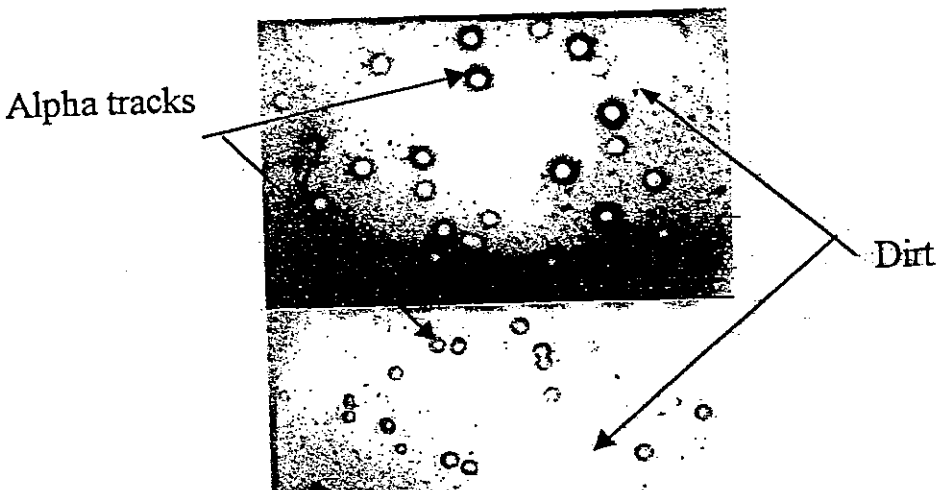


Figure 4.3: Photo showing alpha tracks and dirt in two fields views.

To eliminate the effective background radiation on the results, an unused detector was etched and scanned under an optical microscope and its average number of tracks subtracted from average number of tracks of each detector. The annual effective dose equivalent was calculated from radon concentrations by using the conversion factor of 1 mSv per 20 Bq m^{-3} [8,22,27]. In order to estimate the lifetime risk of radon induced lung cancer, we calculated the radon

exposure in working level months (WLM) per life. The WLM is an exposure rate of one working level (1 WL) for a working month of 170 hours and is equivalent to WL times (hours exposed)/170 [17]. The working level, WL, is given by [7]:

$$WL = F\, C_{Rn}/100 \qquad (4.3)$$

where F is the equilibrium factor between radon and its short –lived daughters which is taken to be 0.5 and C_{Rn} represents radon concentration in PCi L^{-1} in dwelling. Assuming that the working time is 8 hours per day for six days in a week and four weeks in a month of 10.5 working months per year. Also, assuming that the employees start their work at the age of 23 years and retire at the age 65 years, then the WLM per year and the WLM per life are given by:

WLM /year = WLM × 10.5 (working months per year) (4.4)

WLM / life = WLM / year × 42 (working years per life) (4.5)

Eventually, the lifetime risk of radon induced lung cancer was evaluated according to the risk coefficient factor of 1.5×10^{-4}/ WLM per life [63].

Chapter five

Results and Discussion

5.1– Radon Results Obtained Using the Calibration Factor (5.3 ± 0.5)

The results, using the calibration factor 5.3 ± 0.5, of indoor radon concentrations, doses and lifetime risk of radon induced lung cancer in the investigated hospitals and health centers of Nablus city are summarized in tables 5.1 through 5.7. The radon concentrations are also represented by histogram graphs which are depicted in fig 5.1–5.7.

Table 5.1: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL –Watani hospital

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (×10 - 4)	Avg of lifetime risk (× 10 - 4)	Stdev of lifetime risk (× 10 - 4)
Internal kidney	125.00	11.25	18.78			0.94			1.26	2.00		
Internal archives	82.00	19.90	50.64			2.53			3.41	5.10		
Mid storehouse	125.00	5.40	9.01			0.45			0.61	0.90		
Midarchives	82.00	29.50	75.07	48.57	43.96	3.75	2.43	2.20	5.05	8.00	4.67	3.69
External clinics (heart)	125.00	9.40	15.69			0.78			1.06	2.00		
Rays files room	125.00	73.21	122.21			6.11			8.23	10.00		

Avg: average, stdev: standard deviation, dose: annual effective equivalent dose, lifetime risk: lifetime risk of radon induced lung cancer.

Table 5.2: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL –Ethad hospital

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (× 10 - 4)	Avg of lifetime risk (× 10 - 4)	Stdev of lifetime risk (× 10 - 4)
Pharmacy warehouse	124.00	19.79	33.30			1.67			2.24	3.36		
Pharmacy store (1)	124.00	9.33	15.70			0.79			1.06	1.59		
Pharmacy store (2)	124.00	3.90	6.56			0.33			0.44	0.66		
Pharmacy (interior)	147.00	5.50	7.81	26.41	47.44	0.39	1.32	2.37	0.53	0.79	2.67	4.80
Sewing room	124.00	10.80	18.17			0.91			1.22	1.83		
Washing room	147.00	2.50	3.55			0.18			0.24	0.36		
Oxygen room	124.00	5.36	9.02			0.45			0.61	0.91		
Bed sheet warehouse	124.00	3.50	5.89			0.29			0.40	0.60		
Kitchen store	124.00	3.00	5.05			0.25			0.34	0.51		
New building (main trusts)	124.00	94.50	159.02			7.95			10.70	16.10		

Table 5.3: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of Rafedia hospital

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (× 10 - 4)	Avg of lifetime risk (× 10 - 4)	Stdev of lifetime risk (× 10 - 4)
Archives	124.00	135.38	227.81			11.39			15.33	23.00		
Archives	124.00	114.00	191.83			9.59			12.91	19.40		
Maintenance room	124.00	23.10	38.87			1.94			2.62	3.92		
Maintenance store	124.00	56.40	94.91	73.02	82.03	4.75	3.65	4.10	6.39	9.58	7.37	8.29
Sewing room	124.00	11.32	19.05			0.95			1.28	1.92		
Carpentry rooom	124.00	3.14	5.28			0.26			0.36	0.53		
Sterilization room	124.00	10.80	18.17			0.91			1.22	1.83		
Requisites room (external)	124.00	18.10	30.46			1.52			2.05	3.08		
Sleeping room (maintenance)	124.00	18.30	30.79			1.54			2.07	3.11		

Table 5.4: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL –Enjeli hospital

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (×10 - 4)	Avg of lifetime risk (× 10 - 4)	Stdev of lifetime risk (× 10 - 4)
Kitchen	131.00	8.88	14.14			0.71			0.95	1.43		
Kitchen office	131.00	17.28	27.52			1.38			1.85	2.78		
Kitchen store	131.00	6.07	9.67	18.92	7.02	0.48	0.95	0.35	0.65	0.98	1.91	0.71
Pharmacy	131.00	13.67	21.77			1.09			1.47	2.20		
Big hole	131.00	13.50	21.50			1.08			1.45	2.17		

Table 5.5: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL–Tadamon health center

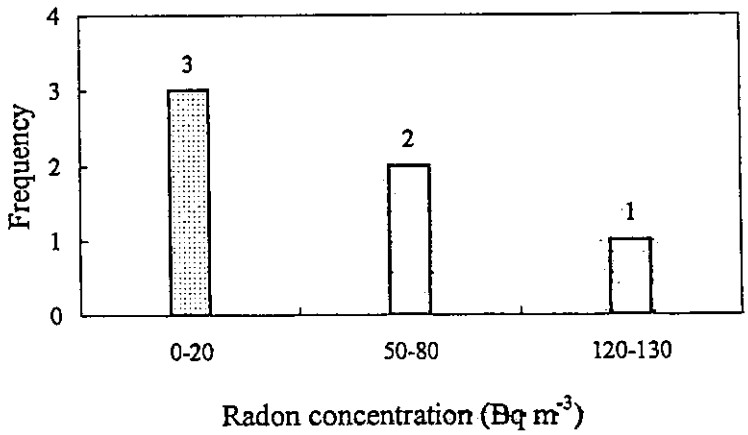
Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (× 10 - 4)	Avg of lifetime risk (× 10 - 4)	Stdev of lifetime risk (× 10 - 4)
Surgery room (old)	131.00	13.07	20.82			1.04			1.40	2.10		
Near the surgery room	131.00	48.00	76.46			3.82			5.15	7.72		
Near the surgery room	131.00	39.94	63.62			3.18			4.28	6.42		
Eyes room (exterior)	131.00	41.36	65.88	43.79	26.23	3.29	2.19	1.31	4.43	6.65	4.42	2.65
Eyes room (interior)	131.00	40.28	64.16			3.21			4.32	6.48		
Lithority room	131.00	7.00	11.15			0.56			0.75	1.13		
Lithority waiting room	131.00	11.07	17.63			0.88			1.19	1.78		
Sterilization room	131.00	19.20	30.58			1.53			2.06	3.09		

Table 5.6: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL – Rahma health center

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (×10 - 4)	Avg of lifetime risk (×10 - 4)	Stdev of lifetime risk (×10 - 4)
Laboratory	130.00	24.70	39.65			1.98			2.67	4.00		
Pharmacy	130.00	16.23	26.05			1.30			1.75	2.63		
Administration room	130.00	26.50	42.53	36.37	7.21	2.13	1.82	0.36	2.86	4.29	3.67	0.73
Accounting room	130.00	23.20	37.24			1.86			2.51	3.76		

Table 5.7: Summary of the results of radon in the four hospital and the two health centers

Measurement place	Concentration (B q m^{-3})			Dose (mSv)			Lifetime risk (× 10^{-4})		
	Range	Avg	Stdev	Range	Avg	Stdev	Range	Avg	Stdev
AL -Watani hospital	9.01-122.21	48.57	43.96	0.45-6.11	2.43	2.20	0.9-10.00	4.67	3.69
AL-Ethad hospital	3.55-159.02	26.41	47.44	0.18-7.95	1.32	2.37	0.36-16.10	2.67	4.80
Rafedia hospital	5.28-227.81	73.02	82.03	0.26-11.39	3.65	4.10	0.53-23.00	7.37	8.29
AL-Enjeli hospital	9.67-27.52	18.92	7.02	0.48-1.38	0.95	0.35	0.98-2.78	1.91	0.71
AL -Tadamon health center	11.15-76.46	43.79	26.23	0.56-3.82	2.19	1.31	1.13-7.72	4.42	2.65
AL -Rahma health center	26.05-42.53	36.37	7.21	1.30-2.13	1.82	0.36	2.63-4.29	3.67	0.73



Figuer 5.1 : Frequency histogram of radon in AL- Watani hospital

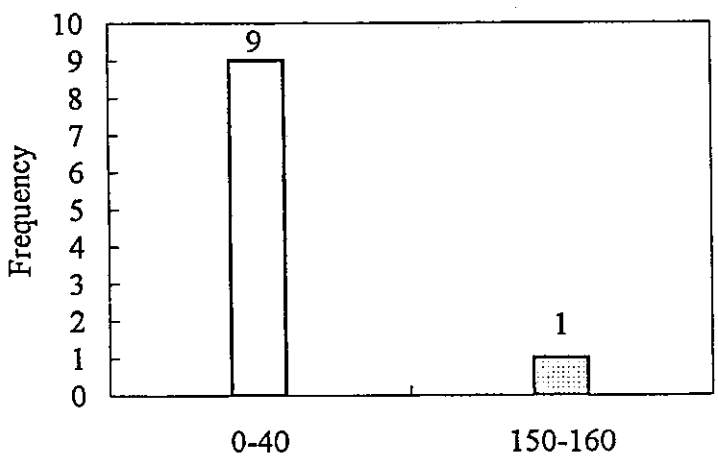


Figure 5.2:Frequency histogram of radon in AL -Ethad hospital

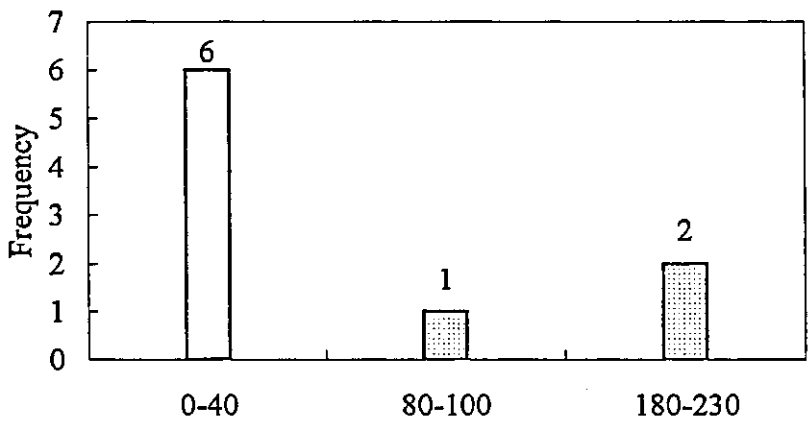


Figure 5.3: Frequency histogram of radon in Rafedia hospital

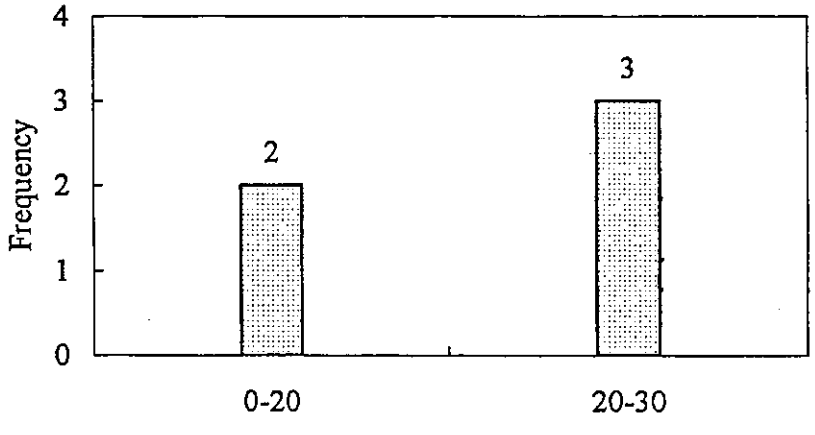


Figure 5.4:Frequency histogram of radon in AL-Enjeli hospital

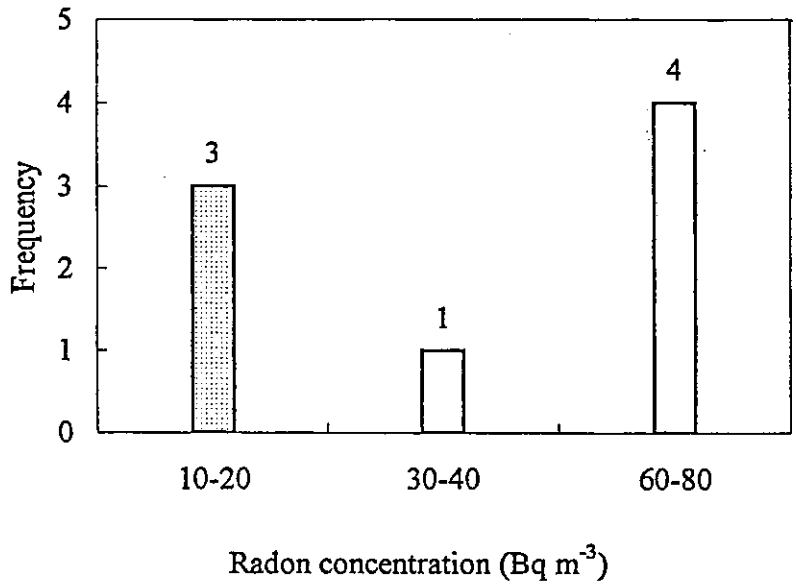


Figure 5.5: Frequency histogram of radon in AL - Tadamon health center

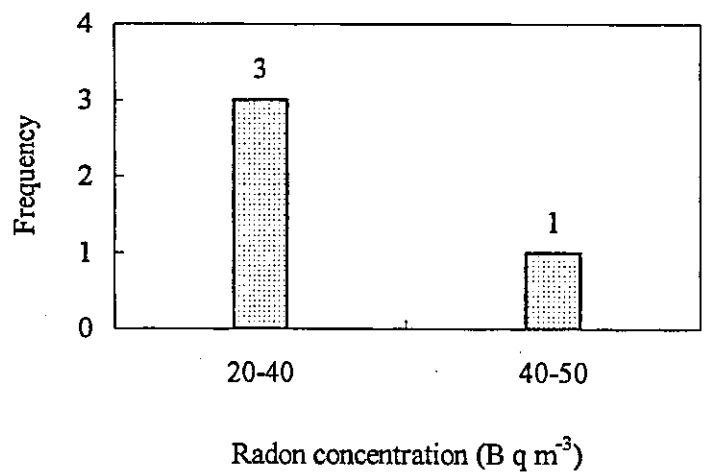


Figure 5.6: Frequency histogram of radon in AL -Rahma health center

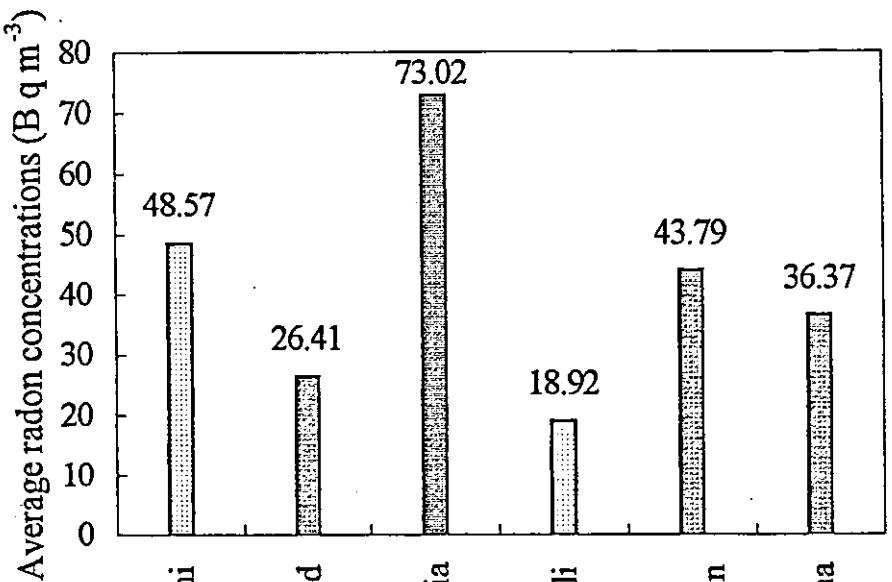


Figure 5.7: Frequency histogram of the average radon concentrations in the four hospitals and the two health centers

5.2– Radon Results Obtained Using the Calibration Factor (6.68 ± 0.02)

Tables 5.8–5.14 give the results of indoor radon concentrations, doses and lifetime risk of radon induced lung cancer, in the various hospitals and health centers using the calibration (6.68 ± 0.02). The histogram graphs 5.8 –5.14 represent the radon concentrations in the studied hospitals an health centers. Table 5.15 compares the data obtained from kodalpha films and those from CR –39 detectors using the two calibration factors. The correlation between the radon concentrations measured using the kodalpha films and those measured using the CR –39 and calibration factor of (5.3 ± 0.5) is represented in fig. 5.15. Fig. 5.16 represents the correlation between the radon concentrations obtained by the above mentioned two methods and using a calibration factor of (6.68 ± 0.02) for the CR –39 detector.

Table 5.8: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL –Watani hospital

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (×10-4)	Avg of lifetime risk (× 10 -4)	Stdev of lifetime risk (× 10 -4)
Internal kidney	125.00	11.25	23.67			1.18			1.59	2.39		
Internal archives	82.00	19.90	63.82			3.19			4.30	6.44		
Mid storehouse	125.00	5.40	11.36			0.57			0.76	1.15		
Midarchives	82.00	29.50	94.61	61.21	55.41	4.73	3.06	2.77	6.37	9.55	6.19	5.61
External clinics (heart)	125.00	9.40	19.78			0.99			1.33	2.00		
Rays files room	125.00	73.21	154.03			7.70			10.4	15.60		

Table 5.9: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL –Ethad hospital

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (×10-4)	Avg of lifetime risk (× 10 -4)	Stdev of lifetime risk (× 10 -4)
Pharmacy warehouse	124.00	19.79	41.97			2.10			2.83	4.24		
Pharmacy store(1)	124.00	9.33	19.79			0.99			1.33	2.00		
Pharmacy store(2)	124.00	3.90	8.27			0.41			0.56	0.84		
Pharmacy (interior)	147.00	5.50	9.84	33.28	59.80	0.49	1.66	2.99	0.66	0.99	3.36	6.03
Sewing room	124.00	10.80	22.91			1.15			1.54	2.31		
Washing room	147.00	2.50	4.47			0.22			0.30	0.45		
Oxygen room	124.00	5.36	11.37			0.57			0.77	1.15		
Bed sheet warehouse	124.00	3.50	7.42			0.37			0.50	0.75		
Kitchen store	124.00	3.00	6.36			0.32			0.43	0.64		
New building (main trusts)	124.00	94.50	200.43			10.02			13.49	20.20		

Table 5.10: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of Rafedia hospital

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (×10-4)	Avg of lifetime risk (× 10 -4)	Stdev of lifetime risk (× 10 -4)
Archives	124.00	135.38	287.13			14.36			19.33	29.00		
Archives	124.00	114.00	241.78			12.09			16.27	24.40		
Maintenance room	124.00	23.10	48.99			2.45			3.30	4.95		
Maintenance store	124.00	56.40	119.62	92.03	103.38	5.98	4.60	5.17	8.05	12.10	9.29	10.44
Sewing room	124.00	11.32	24.01			1.20			1.62	2.42		
Carpentry rooom	124.00	3.14	6.66			0.33			0.45	0.67		
Sterilization room	124.00	10.80	22.91			1.15			1.54	2.31		
Requisites room (external)	124.00	18.10	38.39			1.92			2.58	3.88		
Sleeping room (maintenance)	124.00	18.30	38.81			1.94			2.61	3.92		

Table 5.11: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL –Enjeli hospital

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (×10-4)	Avg of lifetime risk (× 10 -4)	Stdev of lifetime risk (× 10 -4)
Kitchen	131.00	8.88	17.83			0.89			1.20	1.80		
Kitchen office	131.00	17.28	34.69			1.73			2.33	3.50		
Kitchen store	131.00	6.07	12.19	23.85	8.85	0.61	1.19	0.44	0.82	1.23	2.41	0.89
Pharmacy	131.00	13.67	27.44			1.37			1.85	2.77		
Big hole	131.00	13.50	27.10			1.36			1.82	2.74		

Table 5.12: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL –Tadamon health center

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (×10-4)	Avg of lifetime risk (× 10 -4)	Stdev of lifetime risk (× 10 -4)
Surgery room (old)	131.00	13.07	26.24			1.31			1.77	2.65		
Near the surgery room	131.00	48.00	96.36			4.82			6.49	9.73		
Near the surgery room	131.00	39.94	80.18			4.01			5.40	8.10		
Eyes room (exterior)	131.00	41.36	83.03	55.19	33.06	4.15	2.76	1.65	5.59	8.38	5.57	3.34
Eyes room (interior)	131.00	40.28	80.87			4.04			5.44	8.16		
Lithority room	131.00	7.00	14.05			0.70			0.95	1.42		
Lithority waiting room	131.00	11.07	22.22			1.11			1.50	2.24		
Sterilization room	131.00	19.20	38.55			1.93			2.59	3.89		

Table 5.13: indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of AL –Rahma health center

Measurement place	exposure time (day)	Avg number of tracks	Concentration (Bq m-3)	Avg concentration	Stdev of concentration	Dose (mSv)	Avg dose	Stdev of dose	WLM per life	Lifetime risk (×10-4)	Avg of lifetime risk (× 10 -4)	Stdev of lifetime risk (× 10 -4)
Laboratory	130.00	24.70	49.97			2.50			3.36	5.04		
Pharmacy	130.00	16.23	32.83			1.64			2.21	3.31		
Administration room	130.00	26.50	53.61	45.84	9.09	2.68	2.29	0.45	3.61	5.41	4.63	0.92
Accounting room	130.00	23.20	46.93			2.35			3.16	4.74		

Table 5.14: Summary of the results of radon in the four hospitals and the two health centers

Measurement place	Concentration (B q m^{-3})			Dose (mSv)			Lifetime risk (× 10^{-4})		
	Range	Avg	Stdev	Range	Avg	Stdev	Range	Avg	Stdev
AL -Watani hospital	11.36-154.03	61.21	55.41	0.57-7.70	3.06	2.77	1.15-15.60	6.19	5.61
AL-Ethad hospital	4.47-200.43	33.28	59.80	0.22-10.02	1.66	2.99	0.45-20.20	3.36	6.03
Rafedia hospital	6.66-287.13	92.03	103.38	033-14.36	4.60	5.17	0.67-29.00	9.29	10.44
AL-Enjeli hospital	12.19-34.69	23.85	8.85	061-1.73	1.19	0.44	1.23-3.50	2.41	0.89
AL -Tadamon health center	14.05-96.36	55.19	33.06	0.70-4.82	2.76	1.65	1.42-9.73	5.57	3.34
AL -Rahma health center	32.83-53.61	45.84	9.09	1.64-2.68	2.29	0.45	3.31-5.41	4.63	0.92

Table 5.15: Correlation between the radon concentration of kodalpha films and the corresponding concentrations of CR –39 detectors

Measurement place	Radon concentration (Bq m-3)		
	Kodalpha films	CR-39 detectors	
		Calibration factor	
		5.3 ± 0.5	6.68 ± 0.02
AL -Watani hospital	62.00	50.64	63.67
AL-Ethad hospital	24.00	15.70	19.70
	201.00	159.02	200.43
	19.00	9.02	11.37
Rafedia hospital	24.00	19.05	24.01
AL-Enjeli hospital	28.00	27.52	34.69
	37.00	21.77	27.44
AL -Tadamon health center	33.00	20.82	26.44
	36.00	30.58	38.55
	83.00	63.62	80.18
	84.00	64.16	80.87
	91.00	76.46	96.36
AL -Rahma health center	55.00	42.53	53.61

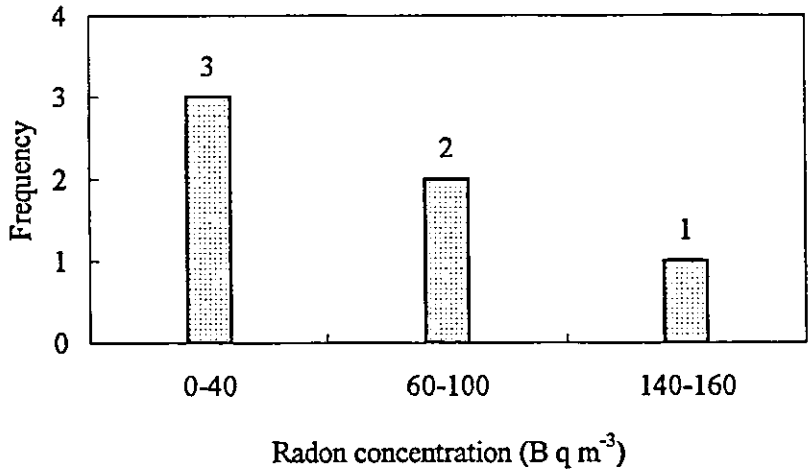


Figure 5.8: Frequency histogram of radon in AL - Watani hospital

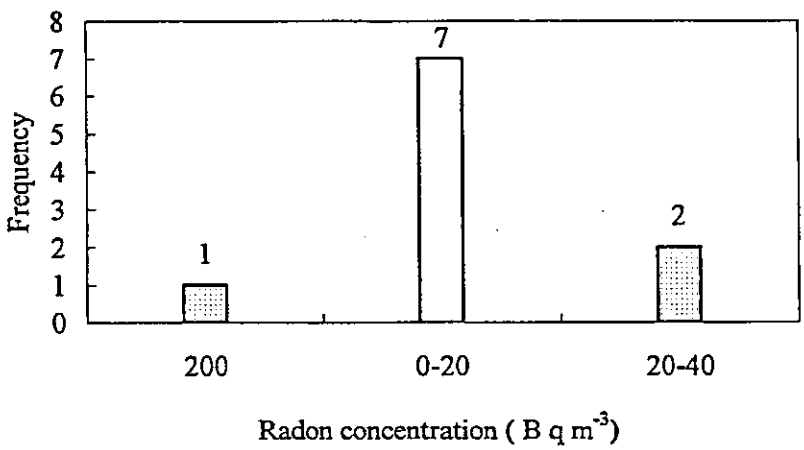


Figure 5.9: Frequency histogram of radon in AL-Ethad hospital

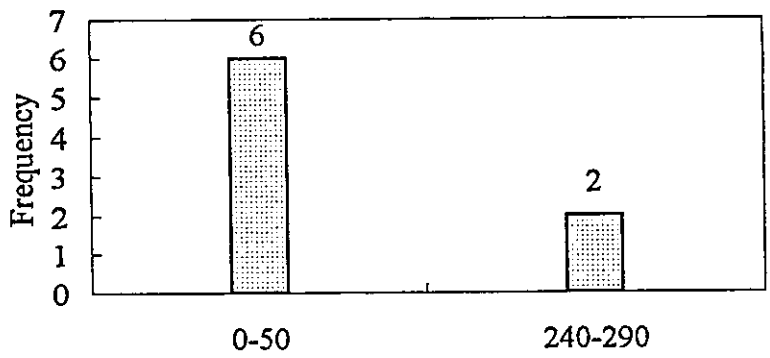


Figure 5.10: Frequency histogram of radon in Rafedia hospital

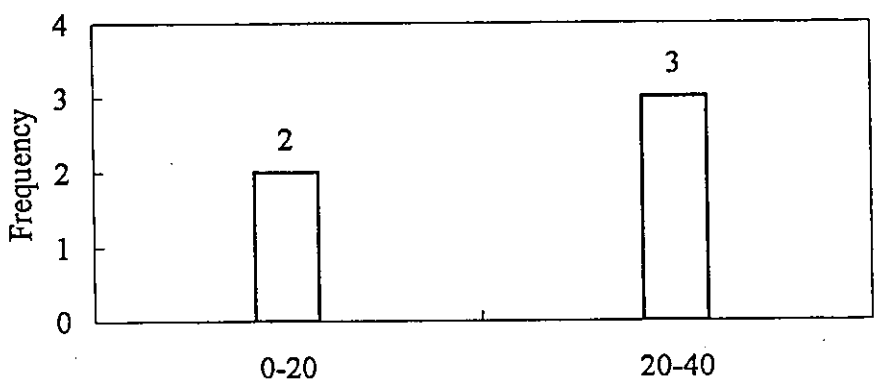


Figure 5.11:Frequency histogram of radon in AL-Enjeli hospital

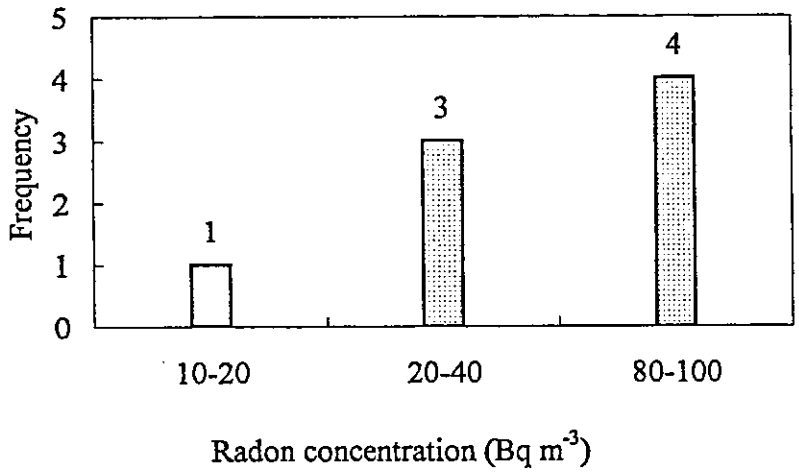


Figure 5.12: Frequency histogram of radon in AL-Tadamon health center

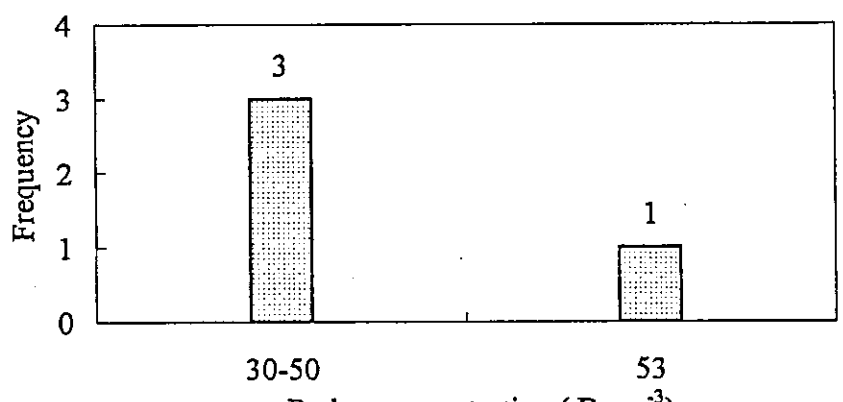


Figure 5.13: Frequency histogram of radon in AL-Rahma health center

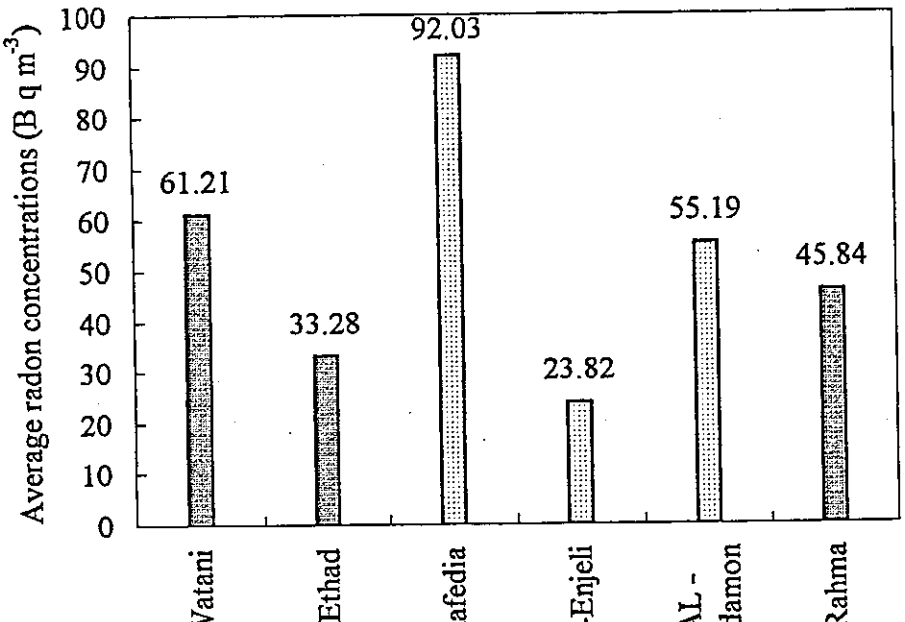


Figure 5.14: Frequency histogram of the average radon concentrations in the four hospitals and the two health centers

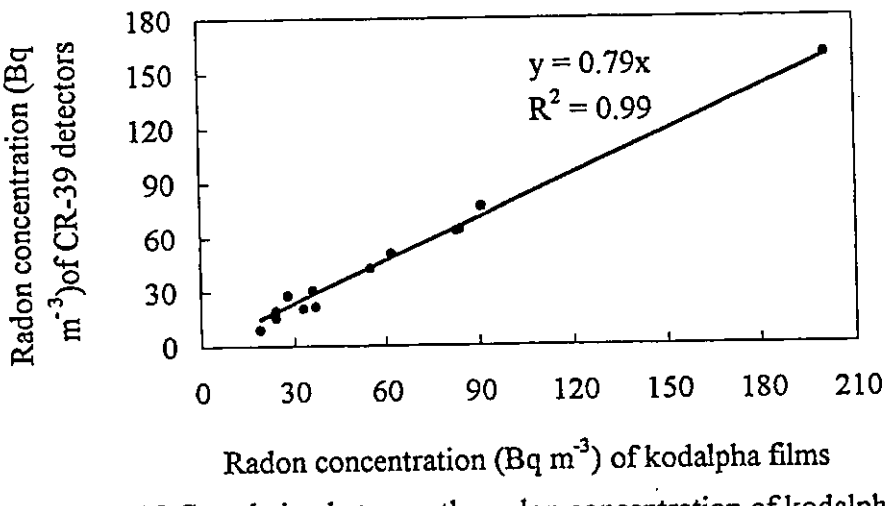


Figure 5.15:Correlation between the radon concentration of kodalpha and CR-39 detectors with calibration factor (5.3 ± 0.5)

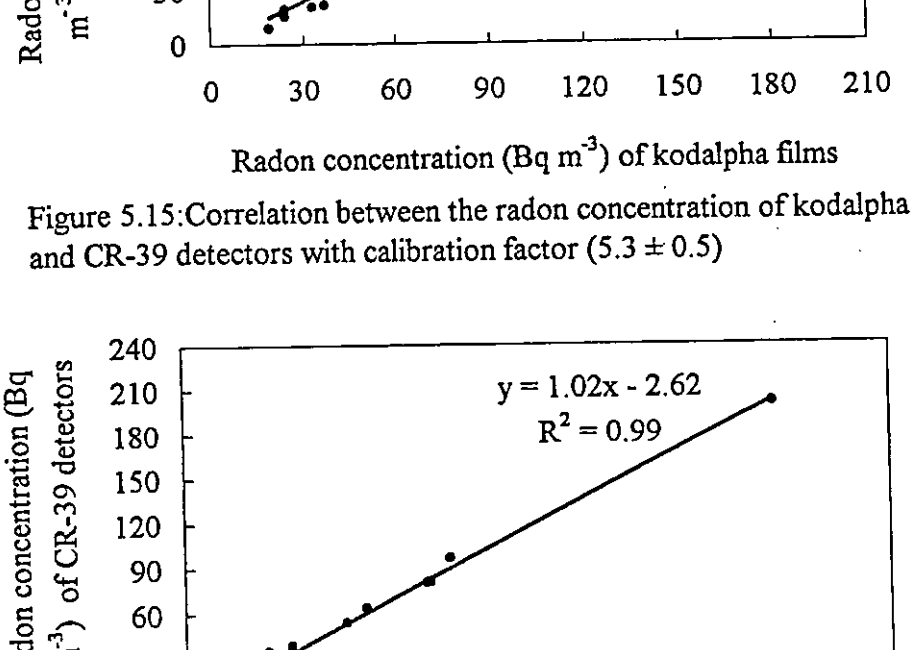


Figure 5.16: Correlation between the radon concentration of kodalpha and CR-39 detectors with calibration factor (6.68 ± 0.02)

5.3 – Discussion

As can be seen from the data plotted in fig. 5.16, a highly significant linear correlation (R^2 =0.99) is obtained when using our calibration factor of (6.68 ± 0.02) for the calculation of indoor radon concentrations from the CR –39 detectors. Also the single values of the radon concentrations that were obtained from using the CR –39 detectors and calculated by using the calibration factor (6.68 ± 0.02) are more comparable, than those calculated by the calibration factor (5.3 ± 0.5), with those obtained from the kodalpha detectors. Therefore, only the results obtained by this calibration factor (6.68 ± 0.02) will be discussed.

Indoor radon concentrations ranged in AL –Watani hospital from 11.36 in mid storehouse to 154.03 Bq m^{-3} in rays files room. The corresponding dose and lifetime risk of radon induced lung cancer, respectively, range from 0.57 to 7.70 mSv/y and from 1.15 $\times 10^{-4}$ to 15.60$\times$ 10^{-4} (see tables 5.8

and 5.14). The average radon concentration and consequently the dose and lifetime risk are, respectively, 61.21 Bq m^{-3}, 3.06 mSv/y and 6.19 $\times 10^{-4}$. The elevated radon concentration, as expected, is due to the lack of ventilation, presence of cracks and poor painting. In comparison with U.S.A. action level (150 Bq m^{-3}) and U.K. action level (200 Bq m^{-3}), it can be concluded that AL–Watani hospital has no radon problem. The radon concentrations in AL–Ethad hospital, in seven locations, are less than 20 Bq m^{-3} (see table 5.9 and fig 5.9). The elevated value in main trusts room is due to poor ventilation. This room is small in size and houses the control board of the hospital electricity and is rarely opened, so it is not suitable as a study place and can be excluded from the study. The average radon concentration and the corresponding dose and lifetime risk are, respectively, 33.28 Bq m^{-3}, 1.66 mSv/y and 3.36 $\times 10^{-4}$. There is no radon problem in AL –Ethad. In Rafedia hospital the concentration

varied from 6.66 in carpentry room to 287.13 Bq m^{-3} in archives (see tables 5.10, 5.14). It is also to be noted that six out of nine locations have radon concentration values falling below 50 Bq m^{-3}. The average concentration was 92.02 Bq m^{-3} and the corresponding dose and lifetime risk are 4.60 mSv/y and 9.29×10^{-4}, respectively. The observed high radon concentration in archive is due to very poor ventilation, and the noticeable cracks in the floor and the walls. Archive is a big underground store used to save the patients files. Two dosimeters were used to measure radon in the archive and gave two different values, 287.12 and 241.78 Bq m^{-3} (see table 5.10). The lower value was obtained from the dosimeter that was placed just beside the door. This confirms the essential role played by ventilation in reducing the radon concentration. The high radon concentration in archive can be reduced by in creasing the air exchange rate with outside, closing the cracks and repainted. Except for the archive there

is no radon problem in Rafedia hospital. It is interesting to note that all of the concentrations in AL–Enjeli hospital were below 40 Bq m^{-3} (see table 5.11 and fig. 5.11). The minimum value of 12.19 Bq m^{-3} and the maximum value of 34.69 Bq m^{-3} were found in kitchen store and kitchen office, respectively. The average concentration and the corresponding dose and lifetime risk are, respectively, 23.85 Bq m^{-3}, 1.19 mSv/y and 2.41 $\times 10^{-4}$ (see table 5.11 and fig 5.11). The low concentrations in this hospital are due to the fact that the hospital buildings are relatively new with good painting and ventilation. In AL –Tadamon health center the concentration varied from 14.05 in the lithotrity room 96.36 Bq m^{-3} near the surgery room (see tables 5.12 and 5.14). The average concentration was 55.19 Bq m^{-3} and the corresponding dose and lifetime risk of radon induced lung cancer are, respectively, 2.76 mSv/y and 5.57 $\times 10^{-4}$ (see table 5.14 and fig 5.14). On the average AL–Tadamon has no

radon problem. Radon concentration up to 53.61 Bq m^{-3} was found in the administration room in AL –Rahma health center. The value of radon concentration dropped to 32.83 Bq m^{-3} in the pharmacy room in AL –Rahma health center (see tables 5.13 and 5.14). The average concentration and consequently the corresponding dose and lifetime risk of radon induced lung cancer were evaluated and found to be, respectively, 45.84 Bq m^{-3}, 2.68 mSv/y and 4.63×10^{-4} (see table 5.14 and fig 5.14).

5.4 – Conclusion

Using CR –39 detectors Indoor radon concentrations were calculated in four hospitals and two health centers in Nablus City using two calibration factors (5.3 ± 0.5) and (6.68 ± 0.02). On the basis of these values dose and lifetime risk of radon induced lung cancer were calculated. The values of radon concentrations that resulted from the CR–39

detectors, were compared with the values of radon concentrations obtained from the kodalpha films. The results of indoor radon concentrations using the CR –39 detectors that were calculated by using the two-calibration factors (6.68 ± 0.02) and (5.3 ±0.5) show highly positive linear correlation with results obtained from kodalpha detectors. But the single values of the radon concentrations that were calculated by using the calibration factor (6.68 ± 0.02) are more comparable, than those calculated by the calibration factor (5.3 ± 0.5), with radon concentrations that were obtained from using the kodalpha detectors. The average concentrations of indoor radon were calculated for the four hospitals and two health centers and compared with worldwide mean of 40 Bq m^{-3}. Except in AL –Ethad and AL –Enjeli hospitals, the values of the average indoor radon concentrations were found to be higher than worldwide mean. In comparison with U.S.A. action level of 150 Bq m^{-3} and

U.K. action level of 200 Bq m^{-3}, the results were within the normal values in few places of the investigated hospitals and health centers. It is believed that poor ventilation is the main cause of the radon concentration. Therefore improving ventilation of these places will reduce the radon concentration to acceptable values.

ملخص الدراسة

تم قياس تركيز غاز الرادون في الهواء داخل أربع مستشفيات (الوطني ، الاتحاد ، رفيديا ، الإنجيلي) ومركزين صحيين (مستوصف التضامن ، مستوصف الرحمة). في مدينة نابلس. استخدم في هذه الدراسة ست واربعون (46) كاشفا" من نوع (CR-39) و أربعة عشرا" من نوع (kodalpha). وزعت هذه الكواشف في أماكن عشوائية داخل هذه المستشفيات الأربعة والمركزين الصحيين. فقد خلال الدراسة أربعة كواشف من (CR-39) وكاشف واحد من (Kodalpha). وقد عولجت كواشف (CR-39) كيميائيا" في محلول هيدروكسيد الصوديوم بتركيز (6.25 N) على درجة حرارة C^{o} (2±98) لمدة ساعة . استخدم مجهر ضوئي لمسح الكاشف وحساب متوسط المسارات في وحدة المساحة ومن ثم حساب تركيز غاز الرادون في الهواء . بينما تم قراءة كواشف (kodalpha) في فرنسا.

وجد ان تركيز غاز الرادون يتغير من 11 إلى $Bq\ m^{-3}$ 154 في الوطني ، 4 إلى $Bq\ m^{-3}$ 200 في الاتحاد ، 6 إلى $Bq\ m^{-3}$ 287 في رفيديا ، 12 إلى $Bq\ m^{-3}$ 35 في الإنجيلي، 14 إلى $Bq\ m^{-3}$ 96 في التضامن ، 32 إلى $Bq\ m^{-3}$ 54 في الرحمة . ثم استخدمت التراكيز لحساب خطر الإصابة في

السرطان وكان متوسط خطر الإصابة بمرض السرطان 6.19×10^{-4} في الوطني، 3.36×10^{-4} في الاتحاد، 9.29×10^{-4} في رفيديا، 2.41×10^{-4} في الإنجيلي، 5.57×10^{-4} في التضامن، 4.63×10^{-4} في الرحمة.

تراكيز غاز الرادون كانت في بعض الأماكن اكبر من الحد الأعلى المسموح به في الولايات المتحدة والذي يساوي ($150\ Bq\ m^{-3}$)، مما يتطلب اتخاذ إجراءات لتخفيض هذه التراكيز.

Appendix A

Mutual relation between the units

$1 pCil^{-1} = 37\ Bq\ m^{-3}$ [16].

$1 WL = 3700\ Bq\ m^{-3}$ [17].

1 rem = 0.1 Sv [21].

$1\ Jh\ m^{-3} = 282.4$ WLM [63].

1 WLM = 4 mSv (for the public) [64].

1 WLM = 5 mSv (for the workers) [64].

Appendix B

Acronyms

ALARA: As low A level as is Reasonable Achievable.

BEIR: Biological Effects of Ionizing Radiation committee (U.S.A.)

EPA: Environmental Protection Agency.

ICRP: International Commission on Radiological Protection.

IAEA: International Atomic Energy Agency.

NCRP: National Council on Radiation Protection and Measurements (U.S.A.).

NRPB: National Radiological Protection Board (U.K.).

UNSCEAR: United Nation Scientific Committee on the Effects of Atomic Radiation.

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